TECHNICAL REPORT

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Hydraulic fluid power — Methods to assess the reliability of hydraulic components —

Part 1: General procedures and calculation method

Transmissions hydrauliques — Méthodes d'évaluation de la fiabilité des composants hydrauliques —

Partie 1: Modes opératoires généraux et méthode de calcul

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 19972-1 was prepared by Technical Committee ISO/TC 131, *Fluid power systems*, Subcommittee SC 8, *Product testing*.

ISO/TR 19972 consists of the following parts, under the general title *Hydraulic fluid power — Methods to assess the reliability of hydraulic components*:

— *Part 1: General procedures and calculation method*

It is possible that other parts will be developed in the future.

Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid or gas under pressure within an enclosed circuit. Fluid power systems are composed of components, and are an integral part of various types of machines and equipment. Efficient and economical production requires highly reliable machines and equipment.

Machine producers need to know the reliability of the components that comprise their machine's fluid power system. Once they know the reliability characteristic of the component, the producers can model the system and make decisions on service intervals, spare parts inventory and areas for future improvement.

There are different methods used to investigate component reliability.

A preliminary design analysis is useful to identify potential failure modes and to reduce their effect on reliability. In addition, calculation of failure rates is possible. When prototypes are available, in-house laboratory reliability tests are run and initial reliability can be determined. Reliability testing is often continued into the initial production run and throughout the production lifetime as a continuing evaluation of the component. Collection of field data is possible when products are operating and data on their failures are available. This, in turn, can be utilized for reduced lab testing on improvements to the products or similar, new products. These methods also offer the user an opportunity to choose the most economical and practical procedure to measure reliability for a given application.

Hydraulic fluid power — Methods to assess the reliability of hydraulic components —

Part 1:
General procedures and calculation method

1 Scope

This part of ISO/TR 19972 provides a means for determining the reliability of hydraulic fluid power components using:

a) estimates from a design analysis;

b) analysis of laboratory testing to failure or suspension;

c) analysis of field data;

d) analysis of a substantiation test.

These methods apply to the first failures without repairs, but exclude certain infant mortality failures. Specific component test procedures and exclusions will be provided in subsequent parts of ISO/TR 19972.

This part of ISO/TR 19972 also provides calculation methods, reporting descriptions and examples of reliability calculations.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1000, *SI units and recommendations for the use of their multiples and of certain other units*

ISO 5598, *Fluid power systems and components — Vocabulary*

ISO 9110-1, *Hydraulic fluid power — Measurement techniques — Part 1: General measurement principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5598 and the following apply.

3.1
B_{10} **life**
L_{10} **life**
life of the component or assembly that has not been altered since its production, where its reliability is 90 %; or time at which 90 % of the population has survived

NOTE The cumulative failure percentage is 10 %.

3.2
component
individual unit (e.g. cylinder, motor, valve, filter, but excluding piping) comprising one or more parts designed to be a functional part of a fluid power system

3.3
mean time to failure
MTTF
mean lifetime of a component that has not been repaired since its production, based on a statistical mean, using times to failure as the definition of failure

3.4
mean cycles to failure
MCTF
mean life, expressed as number of cycles, of a component that has not been repaired since its production, based on a statistical mean, using cycles to failure as the definition of failure

3.5
reliability
probability that a component can perform continuously, without failure, for a specified interval of time when operating under stated conditions

3.6
failure
state at which a component reaches the threshold level or terminates its ability to perform a required function

3.7
termination cycle count
number of cycles on a specimen when it reaches any threshold level for the first time

3.8
threshold level
the value of a performance characteristic (e.g. leakage, flow and current) against which the component's test data is compared

NOTE This is an arbitrary value defined by the experts as the critical value for performance comparisons, but not necessarily indicative of the end of component operation.

4 Units of measurement and symbols

Units of measurement are in accordance with ISO 1000, except for Clause 7 and Annex A, which are based on *The Handbook of Reliability Prediction Procedures for Mechanical Equipment* [9] and use imperial units.

Symbols for the Weibull parameters: β = Slope

η = Characteristic life

t_0 or x_0 = Minimum life

5 Reliability concept

Reliability is the probability (a percentage) that a component will not exceed the threshold level for a specified interval of time or number of cycles when it operates under stated conditions. This probability can be determined by any of the methods described in Clause 6. There are many different statistical distributions that describe the population of failures that result from these methods. Mean time to failure and B_{10} life are common terms used for expressing reliability.

It is also necessary to associate some confidence with a reliability result. This takes into account the fact that results will vary if the process is repeated many times, and the confidence describes probability bounds to the distribution of failures.

To determine reliability scientifically, it is necessary to define failure. This can be evident in field failures, but for the other methods the concept of threshold levels is defined for various performance characteristics. This is necessary because the value of some of these characteristics (e.g. leakage) might not represent a total failure of the component.

Examples of analytical methods and test parameters for which threshold levels might need to be established include:

a) dynamic leakage, both internal and external;

b) static leakage, both internal and external;

c) changes in performance characteristics (e.g. loss of stability, increase in minimum operating pressure, deterioration of flow rate, increase in response time, change in electrical characteristics, performance degradation due to contamination and breakdown of accessory functions).

In addition to these threshold levels, failure can also occur from catastrophic events such as burst, breakage, fatigue or loss of function.

6 Means for determining reliability

6.1 General

Environmental aspects for any of the methods discussed in this part of ISO/TR 19972 will have an influence on the results. Therefore, it is important to record the assumptions used in 6.2, follow the requirements specified for 6.3, record the observations obtained in 6.4, and use the original historical conditions in 6.5.

6.2 Design analysis

Calculation methods can be used to quantify the reliability of hydraulic components. In cases where neither field data or test data are available or tests cannot be carried out economically, calculation methods are recommended to estimate component reliability.

Predicting the reliability of mechanical equipment requires consideration of its exposure to the environment and subjection to a wide range of stress levels (e.g. impact loading). The approach to predicting reliability of mechanical equipment considers the intended operation environment, and determines the effect of that environment at the lowest part level where the material properties can also be considered. The combination of these factors permits the use of engineering design parameters to determine the design life of the equipment in its intended operating environment, and the rate and pattern of failures during design life.

An analysis of a design for reliability and maintenance (R and M) can identify critical failure modes and causes of unreliability as well as providing an effective tool for predicting equipment behaviour. The design evaluation programme includes a methodology for evaluating a design for R and M that considers the material properties, operating environment and critical failure modes at component level. In *The Handbook of Reliability Prediction Procedures for Mechanical Equipment* [9], 19 mechanical components have been identified for which reliability prediction equations have been developed. If a hydraulic component includes more than one mechanical component, the individual mechanical component reliabilities can be combined to establish the total equipment reliability.

A great advantage of this method is that the influence of parameters on the life of a component can be determined. This allows the engineer to improve the design in an early phase of development.

6.3 Laboratory test to failure or suspension

One of the major difficulties encountered in specifying a reliability test is the time it takes to cause a failure without accelerating the test. Accelerated testing, with environmental conditions above those for which the component is rated, is sometimes necessary in order to keep the test time at a reasonable length. The goals and objectives of the test method should be clearly defined.

The primary criterion for determining test acceleration factors is that the failure mode or failure mechanism should not change or be different from that expected from a non-accelerated test.

Two other important factors are the test stand and measurement of parameters. The test stand should be designed to operate reliably within the planned environmental conditions. Its configuration should not affect the results of the test being run on the component. Evaluation and maintenance of the test stand during the reliability test programme is critical. The accuracy of parameter measurement and control of parameter values should be within the specified tolerances to assure accurate and repeatable test results.

Proper test planning is essential in order to have results that accurately predict the component's reliability under specified conditions. The goals and objectives of the test programme should be clearly defined if a supplier and user agree to apply this part of ISO/TR 19972.

6.4 Collection of field data

Collection of field reliability data is an essential element of an effective product reliability programme. It is one of the most valuable sources of data since it represents actual customer/user product experience under working conditions.

Failures occur as a result of manufacturing and material deviations, product overstress in use, design deficiencies, cumulative wear and degradation, and random occurrences. Factors such as product misapplication, operating environment, installation and maintenance practices directly impact product life. Hence the collection of field data is necessary to assess these factors. Therefore, it is very important that details such as product lot identification, date codes and the specific operating environment be recorded.

Communication of objectives and the qualifications of personnel involved in the reporting process are crucial to the success of the data collection effort. It should be recognized that information to be extracted can only be obtained from the data collected. It is essential to be clear about objectives.

Since field data collection relies on people, it is subject to errors, personal biases, omissions and misunderstandings. It is therefore critically important to collect all data using a formal structured procedure and format.

The importance that appropriately trained qualified operations and maintenance personnel can contribute to the completeness and correctness of the data should not be underestimated. However, the design of the data collection system should minimize any bias that could be introduced by the personnel involved.

NOTE It is important to consider the individual's position, experience and objectivity when developing the collection procedures.

Selection of the data to be collected depends on the kind of performance metrics to be evaluated or estimated. The data collection system should provide at least

a) basic product identification information, including total number of units in service,

b) equipment environmental class,

c) environmental conditions,

d) operating conditions,

e) performance measurements,

f) maintenance support conditions,

g) failure description,

h) system changes implemented following occurrence of failure,

i) corrective action and specific details of replacement or repair, and

j) date, time and/or cycles to each failure.

6.5 Substantiation testing

Substantiation testing, based on statistical methods, is an efficient means used to validate the reliability of small sample test populations using historical data to define a population failure distribution.

NOTE This is also known as the Weibayes method.

This method validates a minimum level of reliability for a new population similar to an existing one, but does not result in an explicit value for its reliability. Instead, the testing validates that the reliability of the new population is greater than, or equal to, the reliability target of the test.

The procedure consists of selecting a Weibull shape or distribution factor, β, and calculating the test length required to support substantiation (historical data has shown that β tends to be consistent for a specific failure mode criterion). A test programme is then conducted on a sample of the new population. If the test is successful, the minimum level of reliability is substantiated.

7 Procedures for analysing a design concept

7.1 General

Based on handbooks for mechanical and electronic equipment, failure rates can be calculated for all critical parts of a hydraulic component that can fail in service (see Figure 1). For mechanical equipment, failure rates are calculated with reliability prediction equations that consider material properties, operating environment and design parameters. To predict the reliability of a complete component, the single failure rates are simply added to a component failure rate. The MTTF is the reciprocal of the failure rate.

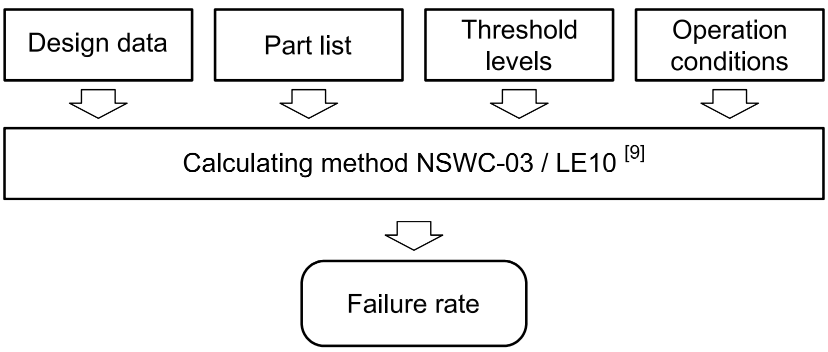

Figure 1 — Flow chart for calculating failure rates

Where integrated electronics are part of a hydraulic component, the failure rate of the electronics can be calculated by using MIL-STD-756B [7], MIL-HDBK-217F [6] or the Telcordia Technologies Special Report SR332 data bank [8].

The Handbook of Reliability Prediction Procedures for Mechanical Equipment [9] is recommended for mechanical parts. This reference is a summary of experiments that have led to an analytical method based on empirical values obtained from that source.

7.2 Design evaluation

Critical components can be identified by simply comparing the parts of the design with the components listed in *The Handbook of Reliability Prediction Procedures for Mechanical Equipment* [9], for example:

a) seals and gaskets;

b) springs;

c) solenoids;

d) valve assembles;

e) bearings;

f) gears and splines;

g) actuators;

h) pumps;

i) filters;

j) brakes and clutches;

k) compressors;

l) electric motors;

m) accumulators and reservoirs;

n) threaded fasteners;

o) mechanical couplings;

p) slider-crank mechanisms;

q) sensors and transducers.

Typical failure modes and failure rate models are defined for each component. The part list should identify all components and the number of parts in a design for the calculation of failure rates.

7.3 Threshold levels

For some components, threshold levels (e.g. allowable leakage) have to be defined in order to calculate the failure rate.

7.4 Operational conditions

Operational conditions have an important influence on the life of a component. All parameters (e.g. fluid pressure, fluid viscosity, temperature, contamination and externally applied loads) are needed to calculate the failure rate of a component.

7.5 Failure rate calculation

For each component there exists a characteristic equation to calculate the failure rate. Also, a base failure rate is given for each component. A generalized equation that adjusts the base failure rate can be established. These characteristics and equations are given in the reference used for the analysis.

For electronic parts, the Telcordia Technologies Special Report SR332 [8] can be used to calculate the failure rate.

The failure rate of the total assembly is the sum of the failure rates calculated for each individual component. Then, the MTTF or MCTF is the reciprocal of the failure rate, λ. An example calculation is given in Annex A.

7.6 Validation statement

Several test programmes were conducted during the development of *The Handbook of Reliability Prediction Procedures for Mechanical Equipment* [9] to verify the identity of failure modes and validate the engineering approach being taken to develop the reliability equations. For example, valve assemblies were procured and tested at the Belvoir Research, Development and Engineering Center in Ft. Belvoir, Virginia. The number of failures for each test was predicted using the equations presented in the Handbook. Failure rate tests were performed for several combinations of stress levels and results compared to predictions. Typical results are shown in Table 1.

Table 1 — Sample test data for validation of reliability

Test [a] series	Valve number	Test cycles to failure	Actual failures/ 10^6 cycles	Average failures/ 10^6 cycles	Predicted failures/ 10^6 cycles	Failure [b] mode no.
15	11	68 322	14,64	14,64	18,02	3
24	8	257 827	—	—	—	1
24	9	131 126	7,63	10,15	10,82	1
24	10	81 113	12,33	—	—	1
24	11	104	—	—	—	2
24	12	110 488	9,05	—	—	1
24	13	86 285	11,59	—	—	1
25	14	46 879	21,33	19,67	8,45	2
25	15	300	—	—	—	3
25	18	55 545	18,00	—	—	1

a Test parameters: System pressure: 3 500 psi
Fluid flow: 100 % rated
Fluid temperature: 90 °C
Hydraulic fluid: MIL-H-83282.

b Failure modes: 1 Spring fatigue;
2 No apparent failure mode;
3 Accumulated debris.