FEDERATION EUROPEENNE DE LA MANUTENTION
SECTION IX

SERIES LIFTING EQUIPMENT

FEM 9.221

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Performance Data of S/R-Machines
Reliability Availability

1. Foreword

The present FEM Rule contains a standard method for determining the reliability and availability of S/R-machines. This method makes it possible to draw conclusions about the throughput which the user of a high-bay warehouse requires from the manufacturer, throughput being defined as the number of storage and retrieval operations per unit of time.

Throughput depends both on the availability of system units and on the cycle time, which is dealt with in FEM 9.851 [1]).

On the basis of theoretical principles, a method for determining performance in practice will be described, in which periods of downtime and malfunctions will be differentiated according to areas of responsibility.

2. Definitions and theoretical principles

2.1 Reliability η_n

The reliability of a discontinuously loaded system unit is equal to the probability of this unit carrying out a particular operation correctly and without malfunctions. In tests, reliability is determined by the quotient

$$\eta_n = \frac{n_r}{n_r + n_f} \qquad (1)$$

where:

n_r = number of correctly carried out operations

n_f = number of operations carried out incorrectly or with faults

The particular operation should be tested with an adequate statistical frequency.

2.2 Availability η_T

The availability of a system unit for a particular operation is equal to the probability of finding that unit, at any given time during the period of operation, in a state which will allow the operation concerned to be carried out correctly and without malfunctions [2]).

In order to determine the availability of individual system units in tests, the unit concerned is considered under clearly defined operating conditions with the planned average loading for a statistically adequate period of time T.

Availability is determined by the quotient

$$\eta_T = \frac{T - T_{aus}}{T} \qquad (2)$$

where:

T = total operating time

T_{aus} = sum of individual periods of downtime

This gives the net operational time

$$T_{net} = T - T_{aus} \qquad (3)$$

The mean downtime is the total downtime T_{aus} divided by the number of failures, n_{aus}:

$$\frac{T_{aus}}{n_{aus}} = \text{MTTR [3])} \qquad (4)$$

Similarly, the mean time without failures is

$$\frac{T - T_{aus}}{n_{aus}} = \text{MTBF [4])} \qquad (5)$$

and, therefore, availability can also be expressed by the quotient

$$\eta_T = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \qquad (6)$$

2.3 Periods of downtime

Each individual period of downtime may be divided into th following sub-periods:

t_1 = period between stoppage of machine and start of search for fault by appropriate personnel

t_2 = time needed to identify cause of failure

t_3 = time needed to correct fault and restore serviceability

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1) FEM 9.851 Performance data of S/R-machines; cycle times

2) In an installation comprising a number of S/R-maschines, the failure of o n e machine will affect the availability of the installation only in part. The availability of the complete installation will be calculated, on the basis of the basic rules of this document, according to the mathematical principles of probability (cf. Appendix A.2).

3) MTTR = mean time to restore

4) MTBF = mean time between failures

Available in English (E), French (F), German (D)

Sources of supply see back page.

3. Practical application

3.1 Performance test

The throughput of a system unit may be checked by performance tests. Cycle times are determined as described in FEM 9.851.

Tests for determining reliability and availability are spread over a certain reference period, which should not be too short. A test of this type may also be carried out for checking agreed performance figures. In this case, the beginning and end of the test period should be agreed between the user and supplier. The duration should be between 1 day and 1 working week, according to the size of the installation.

During the tests, it should be ensured that the machines are subjected to working stresses within the designated limits, as regards both the frequency and spectrum of the loads to be stored, which should be within the limits of the load spectrum for which the machine was designed (cf. FEM 9.512 [5]), as well as an even distribution of storage points over the whole warehouse such as used as the basis for calculating cycle times (cf. FEM 9.851). Stress programmes, such as are found in the filling of a store or during peak periods, are not suitable for this purpose.

3.2 Test certificate

When a test is carried out, the user must complete a fault record as in Form 1 [6], on which should be recorded:

- the times of start and end of operation, with breaks
- the number of correctly completed cycles (n_r)
- the number of incorrectly completed cycles or cycles with failures (n_f)

In addition, the following (time and description) must be entered for each failure:

1. Failure

Time A and nature of failure

2. Fault finding

Time B, arrival of appropriate personnel, and cause of failure established

3. Fault clearance

Time C, start of fault clearance and measures taken

4. Restoration of serviceability (time D)

When the record is evaluated, the periods of downtime mentioned in Section 2.3 may be determined as follows:

$$t_1 = B - A$$
$$t_2 = C - B$$
$$t_3 = D - C$$

3.3 Allocation to areas of responsibility

When tests have been carried out for checking an agreed performance figure, it is necessary to ascribe the causes and sub-periods of downtime to individual areas of responsibility, so that, on the one hand, the user can clearly see if the S/R-machine's performance is as agreed, and, on the other, that the supplier is not attributed with downtime and periods of malfunctioning for which he cannot be held responsible. This assessment should be carried out by the user and supplier together.

When an S/R-machine is assessed, downtime should not be taken into account when the causes are, for instance:

- errors in operation,
- errors in entering data,
- faulty pallets or load units,
- manual storage of goods in automatic installtaions,
- maintenance,

etc.

For the remaining technical faults, a distinction must be made between the sub-periods: t_1, t_2 and t_3

The period t_1 is determined by the user exclusively and cannot be ascribed to the supplier.

The period t_2 is dependent upon causes which may be attributed both to the user and to the supplier. The user's area of responsibility includes, for instance, the training and suitability of maintenance personnel, the availability of the correct tools, etc. The supplier can design the system from the outset so that faults can be identified more easily.

If, in certain cases, time is taken to ascertain the causes of failures in detail, this should not be included as downtime.

The period t_3 may be ascribed to the supplier on the precondition that

- any replacement and wearing parts needed for repairs are kept in stock by the user in accordance with the contractual agreements,
- the maintenance team has the training and the equipment to complete the work within an acceptable period.

3.4 Evaluation

An evaluation sheet such as that in From 2 [7]) may be used for this purpose.

3.4.1 Reliability

The number of cycles recorded in the test certificate gives the reliability by the application of formula (1). If a distinction is to be made on the basis of areas of responsibility, for instance that of the supplier, only the number of the incorrect operations for which he must accept responsibility is to be entered (n_{fL}):

$$\eta_{nL} = \frac{n_r}{n_r + n_{fL}} \qquad (7)$$

3.4.2 Availability

The total downtime is arrived at by using the data from the test certificate in the formula

$$T_{aus} = \sum_{i=1}^{n} (t_1 + t_2 + t_3)_i \qquad (8)$$

Downtime is calculated separately for each area and marked by a subsript, e. g. for the supplier's area of responsibility.

$$T_{aus\,L} = \sum_{i=1}^{n} (t_{2L} + t_{3L})_i \qquad (9)$$

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5) FEM 9.512 Rules for the design of storage and retrieval machines; mechanisms

6) See page 6

7) See page 7

The downtime ascribed to the supplier is related to the net operating time, T_{net} (cf. formula (3)), and determined by formula (10):

$$\eta_{TL} = \frac{T_{net}}{T_{net} + T_{aus\,L}} \qquad (10)$$

It should be borne in mind that operating time for individual S/R-machines can also be recorded for individual S/R-machines, even if the total system is considered as malfunctioning [8]). In calculating the net operating time in such cases, only the periods of downtime and malfunctions of the machine itself may be deducted from the total operating time, and not the downtime of the complete system, especially when deciding whether contractual committments have been kept.

3.4.3 Throughput

Throughput may be calculated using the cycle time as determined in FEM 9.851 and the figures for availability found by the above method. High availability figures and short cycle times have a positive influence on throughput. To a certain extent, the two figures may be used to compensate for each other.

If, for instance, there is a shorter cycle time for the installation during the test than contractually agreed, the availability requirement may be considered to have been met if the agreed throughput has been reached.

4. Standard values

Due to the fact that operator training is not complete during the first months following commissioning of the S/R-machine and that the continued operation of the S/R-machine can reveal malfunctions or inaccuracies which are not always detectable during the works acceptance and commissioning, the supplier can guarantee a throughput rate wich increases with time.

After the first three months following the end of commissioning, availability is generally as high as 90 %, after a further three months, i. e. 6 months after the end of commissioning, it can be as high as 96 %.

Particularly complex installations or especially difficult working conditions may affect these periods and availability figures.

The above figures for availability are made on the following assumptions:

a) The installation is operated exclusively by trained and experienced personnel.
b) Experience shows that downtime occurs more frequently when normal preventive maintenance is not carried out as it should be. The user must, therefore, ensure that preventive maintenance is carried out according to the instructions of the supplier. It is recommended that operating personnel become acquainted with the technical details of the installation by assisting in the erection and commissioning of the S/R-machine, thus enabling them to correct malfunctions occurring later on their own.
c) Inspection and maintenance are not taken into account when calculating availability.
d) Replacement and wearing parts must be available on site according to the recommendations of the supplier.

[8]) E. g. in the case of incorrect commands from a superordinate computer

APPENDIX A.1

Calculation example

6 months after the commissioning of an installation, one S/R-machine was given an operational test for a period of one week.

During the 5 days of single-shift operation, the machine worked a total of $T = 37.3$ hrs [1]). A total downtime of $T_{aus} = 2.1$ hrs was recorded but, of this, only $T_{ausL} = 1.6$ hrs could be attributed to the supplier's area of responsibility (the other 0.5 hrs were due to factors unrelated to the S/R-machine). The availability may therefore be found by applying formula (9) and using the net operating time

$$T_{net} = T - T_{aus} = 37.3 - 2.1 = 35.2$$

to give

$$\eta_{TL} = \frac{T_{net}}{T_{net} + T_{aus\,L}} = \frac{35.3}{35.2 + 1.6} = 0.9565 \quad \text{or} \quad 95.65\,\%$$

As this result is lower than the contractually agreed result of 96 %, the machine's throughput must also be taken into account.

Compared with the agreed 25 cycles per hour (mean cycle time 144 seconds), a mean cycle time of 133 seconds was recorded [2]), i. e. 27 single cycles per hour. As this is 8 % higher than agreed, the machine does meet the availability requirement despite the fact that the agreed figure for availability has not been reached. The machine may, therefore, be accepted.

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1) Taking into account the condition given in the last paragraph of Section 3.4.2

2) Cf. FEM 9.851 Performance data of S/R-maschines; cycle times

APPENDIX A.2

Availability in installations with a number of machines

In order to be able to draw conclusions about availability in an installation with a number of S/R-machines, many peripheral factors must be known, which relate to the exact degree of dependence of the individual units upon each other and the influence which the failure of one machine will have on the complete operation.

For example, in the case that one machine fails completely for a certein period of time, if the other machines can take over the operation, the availability of the complete system $\eta_{T\,ges}$ is only reduced if all the machines are inoperative at the same time. The individual availabilities, η_{T1}, η_{T2}, ... are used to determine the total availability by the following formula:

$$\eta_{T\,ges} = 1 - (1 - \eta_{T1}) \cdot (1 - \eta_{T2}) \cdot \ldots\ldots$$

i. e. with x machines having the same availability

$$\eta_{T\,ges} = 1 - (1 - \eta_{T})^{x}$$

If the machines considered are indeed fully independent and interchangeable, the total availability is a mathematically exact value, which is also produced when the machines are checked in tests as a complete system with one goods-in and goods-out point and which may also be used in superordinate calculations of avalability.

In practice, greater importance is sometimes attached to determining the influence which the availability of one element in the system has on the complete installation. For this purpose, a corrected availability figure, $\eta_{T\,cor}$, may be used, which is calculated using not the complete downtime of a machine but only that proportion which actually affects operation of the installation:

$$\eta_{T\,cor} = \frac{T_{net}}{T_{net} + f_{cor} \cdot T_{aus}}$$

If, for instance, one of two machines in an installation can assume 60 % of the total throughput in the case of a malfunction in the other machine (i. e. total performance is reduced by 40 %), the correction factor is:

$$f_{cor} = (1 - 0.6) = 0.4$$

and the corrected availability is

$$\eta_{T\,cor} = \frac{T_{net}}{T_{net} + 0.4 \cdot T_{aus}}$$

An assessment of the relative importance of individual parts of an installation is thus possible.

Both methods of calculation show clearly, however, that even low availability figures for individual system units pose no problems for the complete installation if, in the case of a malfunction, it is possible to continue operating the system by appropriate user strategy and by the skillful combination of system units.

F.E.M.	**Performance Data of S/R Machines** Reliability Availability	**Form 1**
	Fault Record	**FEM 9.221**

Installation/Machine	Start of operation . . . . Break(s) . . . . End of operation . . . , ...	Date/shift . . . . Logged by: Name . . . . Signed . . . .

Number of storage operations . . . . Malfunctions . . . .

Number of retrieval operations . . . . Malfunctions . . . .

Nº	Time				Description
	Start of fault A	Start of search B	Start of correction C	Operational D	Nature of fault / cause / measures / name

F.E.M.	**Performance Data of S/R-Machines** Reliability Availability **Evaluation Form**	**Form 2** **FEM 9.221**

User	Supplier

Machine data

No. ____________ SWL (kg) ____________

Type ____________ Order no. ____________

Evaluated between . . . . and . . . .

Number of days/shifts . . . .

Number of cycles: total (n)	. . . .	Operating time, in total (T)	. . . . h
with malfunctions (n_f)	. . . .	Downtime, in total (T_{aus})	. . . . h
Incorrect cycles attributable		Downtime attributable	
to the user (n_{fB})	. . . .	to the user (T_{ausB})	. . . . h
to the supplier (n_{fL})	. . . .	to the supplier (T_{ausL})	. . . . h
Correct cycles (n_r)	. . . .	Net operating time (T_{net})	. . . . h

Reliability

In total:

$$\eta_n = \frac{n_r}{n} = \frac{\qquad}{\qquad} = \underline{\underline{\qquad\qquad}}$$

Attributable to the supplier:

$$\eta_{nL} = \frac{n_r}{n_r + n_{fL}} = \frac{\qquad}{\qquad} = \underline{\underline{\qquad\qquad}}$$

Availability

In total:

$$\eta_T = \frac{T_{net}}{T} = \frac{\qquad}{\qquad} = \underline{\underline{\qquad\qquad}}$$

Attributable to the supplier:

$$\eta_{TL} = \frac{T_{net}}{T_{net} + T_{ausL}} = \frac{\qquad}{\qquad} = \underline{\underline{\qquad\qquad}}$$

Agreed availability: ==========

Test certification: S/R-machine accepted yes / no

Place . . . . Date . . . .

. . . .

(Signature of user) (Signature of supplier)

References

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