

TOTAL PRODUCTIVE MAINTENANCE AS A REQUIREMENT OF WORLD CLASS MANUFACTURING

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Abstract

Total Productive Maintenance (TPM) is one of the approaches to World Class Manufacturing which is the application of TQM philosophy and tools in the fields of production, quality assurance and maintenance.

TPM aims at eliminating the wastes due to machine downtime and product quality

- By maximizing equipment effectiveness and productivity and eliminating machine losses;
- By creating team ownership and involvement;
- By promoting continuous improvement through problem solving activities involving people from production, quality assurance and maintenance.

After outlining a possible approach to Total Productive Maintenance, the author examines how the contradiction of productive management strategies aiming at maximum availability with minimum costs can be resolved.

Keywords: total quality management, total productive maintenance, reliability.

1. Introduction

Reliability test of products and production systems is a task comprising both production management and quality management. Our experience shows that most management and organization methods applied in practice are based on classical deterministic approaches. Conscious recognition of stochastic nature of design, organisational and management tasks, preparation of management decisions, approximation of the decisions accordingly, as well as efforts for quantification of inherent risks are found rarely.

Knowledge of reliability parameters and optimum maintenance properties of production and service systems is inevitable for establishment of enterprise production management programs. Real design of production capacities, assessment of results and costs also require quantification of different time funds such as – among others – foreseeable downtimes due to maintenance and catastrophic failures.

After examination of technical reliability on the basis of production data and after reliability-based design of maintenance, capacity and cost estimating methods of stochastic nature considering also interactions of production, reliability and maintenance can and must be elaborated. This approach infers treatment of production and service processes as stochastic processes influenced also by operational and ageing processes.

2. Total Productive Maintenance

On the basis of the research and professional experience of the Total Quality Management Center of Excellence working within the Department of Industrial Management and Business Economics, Total Productive Maintenance is interpreted as a management approach applying TQM philosophy and tools in the field of maintenance [1].

Total Productive Maintenance aims at maximum efficiency (productivity, quality, etc.) through minimizing wastes (downtimes) reducing equipment efficacy. Practically; this objective requires maximization of equipment availability [2].

Key elements of TPM are productive maintenance program (design, maintainability, reliability, end-state analysis), autonomous maintenance and team ownership (operator involvement, team ownership), and continuous improvement (problem solving, trouble shooting).

When carrying out a TPM program, the following lasting loss sources affecting reliability are of key importance:

- breakdown losses;
- set-up and adjustment losses;
- idling and minor stoppage losses;
- reduced speed losses;
- quality defects and rework losses;
- start-up/yield losses.

Reduction of loss resources calls -- among others -- for continuous analysis of production capacity of the equipment and cost analysis.

3. Reliability-Based Capacity Design

Actual effective capacity of a production or service system during the production period tested (e.g. one year) is as follows:

$$C_{p\text{eff}} = C_{p\text{th}} A(t) \quad (1)$$

where

- Cp_{eff} = effective capacity
- Cp_{th} = theoretical capacity
- $A(t)$ = availability factor.

Usually, the steady-state value of the availability factor is of importance in practice. If availability parameters are determined solely on the basis of mean time demands computed from actual data of a former design or operation period, dynamical relations between reliability and maintenance process cannot be taken into account [3].

The reliability-based maintenance design may provide an opportunity for dynamic modelling of the availability parameters. It is observed in practice that the cost minimizing objective functions for determining the optimum maintenance order rarely give sharp optimum, thus, the operator may select the values of the maintenance distance out of a wide range. At the same time, significantly different availability parameters may belong to maintenance cycles to be considered in respect of cost minimum [4, 5].

Interpretation of availability parameters suitable also for dynamic testing of reliability and the role of maintenance will be demonstrated by the example of the maintenance strategy with flexible cycles. In this strategy preventive inspection of the given system element will be only carried out if this unit has survived the prescribed maintenance distance without any failure. The optimum period may be selected both by minimizing the specific operation costs and by maximizing the availability factor .

The objective function minimizing the specific operation cost is as follows:

$$c_0(t_d) = \frac{C_1 F(t_d) + C_2 R(t_d)}{T_M} \rightarrow \min, \quad (2)$$

where

C_1 - mean costs of the repair of the catastrophic failure,

C_2 - mean costs of preventive maintenance,

T_M - mean working time without any failure during the maintenance distance t_d :

$$T_M = \int_0^{t_d} R(t) dt \quad (3)$$

In the case of the flexible maintenance strategy, the availability factor interpreted for the period in question is as follows:

$$A(t_d) = \frac{T_M}{T_M + T_{R,1} F(t_d) + T_{R,2} R(t_d)} \rightarrow \max, \quad (4)$$

where

$T_{R,1}$ — time necessary for repair of the catastrophic failure,

$T_{R,2}$ — time necessary for preventive maintenance.

In addition to practical experience, it can be proved that minimization of the specific operation costs and the maximization of the availability factor require a maintenance intensity (maintenance distance) essentially differing from each other. It can be proved that at the extreme values of (2) and (4)

$$\lambda(t_{d,\text{opt}}) \int_0^{t_{d,\text{opt}}} R(t) dt - F(t_{d,\text{opt}}) = \left\{ \begin{array}{l} \frac{C_1}{C_1 - C_2} \\ \frac{T_{R,2}}{T_{R,2} - T_{R,1}} \end{array} \right\}, \quad (5)$$

where $\lambda(t)$ — failure rate.

We can say that in the case of the flexible maintenance strategy cited as example, the optimum maintenance distance (t_d) obtained by minimization of the specific operation costs agrees with the maintenance distance yielding the maximum availability only in the case when the ratio of the costs of catastrophic failures and preventive maintenance (C_1/C_2) is the same as the relevant time ratio ($T_{R,1}/T_{R,2}$).

Fig. 1 shows the cost function $c_0(t_d)$ and availability function $A(t_d)$ in the case of threefold cost ratio and different time ratios. The distribution of the assumed failure probability $F(t)$ is a Weibull distribution:

$$F(t) = 1 - e^{-7 \cdot t^{2.0}}$$

For example, if a fivefold time ratio belongs to a threefold cost ratio, the maximum availability can be assured only by a more intensive maintenance than the one belonging to the cost minimum. As this involves higher operation costs as well, only a comprehensive operation design can decide on the basis of which objective function it is prudent to design maintenance, i.e. the optimum strategy can be selected only by coordinated design of production and maintenance. Separation of production and maintenance design in the above problem may result in considerable losses.

In selecting the optimum strategy, among others, break-even computations may be of help.

4. Reliability-Based Cost Estimation

When computing concretely, costs affected by capacity exploitation returns from sales, variable costs, contribution margins and fixed costs must be es-

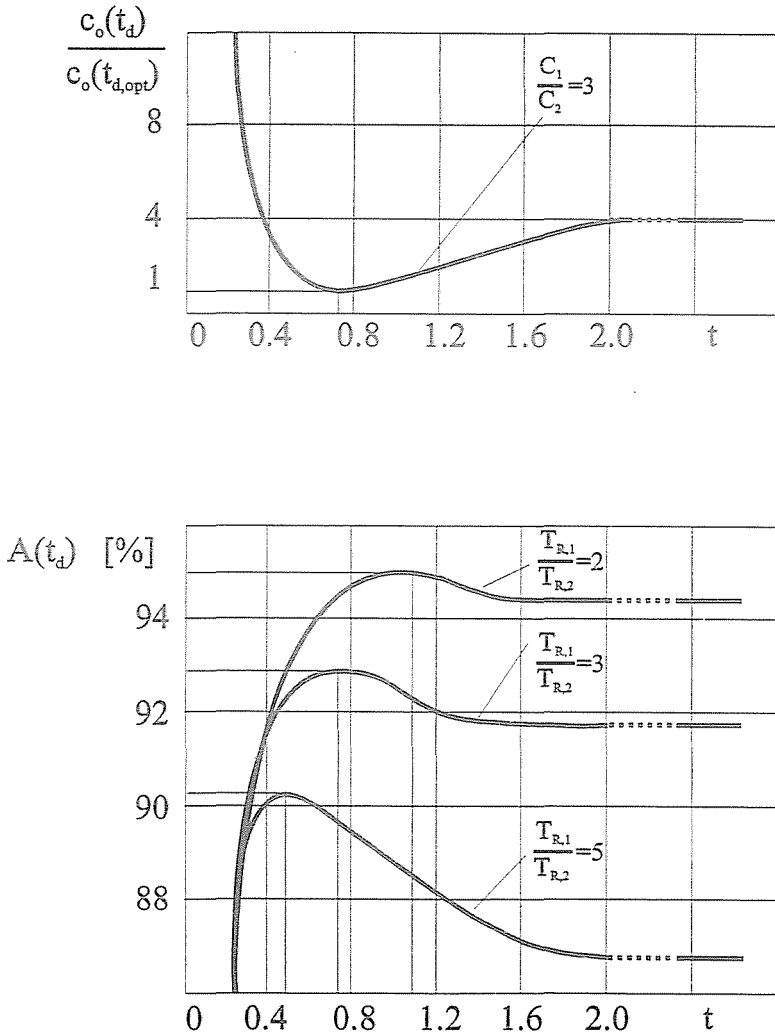


Fig. 1. Specific operation costs and availability factor vs. time

timated by taking both the specific operation costs and the belonging availability factor into consideration. This way it can be decided whether the maintenance strategy based on minimization of the specific operation costs or on maximization of the availability factor yields the higher profit [5].

It can be stated that the system working with the minimum operation costs (STRATEGY-1) gives a smaller availability factor even in the case of optimum maintenance intensity than the system designed for maximum availability (STRATEGY-2) with maintenance intensity of $t_{d,2,opt} < t_{d,1,opt}$ and operation costs $c_{0,2} > c_{0,1}$.

The following cost coverage model permits choice between both possible strategies (Table 1).

Table 1
Break-even analysis

STRATEGY-1			STRATEGY-2	
	$c_{0,1,min}$ (\$/h)	<		$c_{0,2}$ (\$/h)
	$t_{d,1,opt}$ (h)	>		$t_{d,2,opt}$ (h)
	A_1 (%)	<		$A_{2,max}$ (%)
S	$s \cdot C_{pth} \cdot A_1$			$s \cdot C_{pth} \cdot A_{2,max}$
$-K_p$	$-k_p \cdot C_{pth} \cdot A_1$			$-k_p \cdot C_{pth} \cdot A_{2,max}$
F	$-(s - k_p) \cdot C_{pth} \cdot A$			$-(s - k_p) \cdot C_{pth} \cdot A_{2,max}$
$-K_{fa}$	$-K_{fa}$			$-K_{fa}$
$-K_{fb}$	$-c_{0,1,min} \cdot C_{pth}$			$-c_{0,2,min} \cdot C_{pth}$
P	P_1			P_2

The basic philosophy of the model is that knowing the specific returns from sales s (\$/h) and specific variable costs k_p (\$/h), the capacity C_{peff} must be used when determining total returns from sales S (\$/year) and total variable costs K_p (\$/year)

$$C_{peff} = C_{pth} \cdot A \quad (\$/year). \quad (6)$$

The attainable profit (P) will be obtained as the difference of the total contribution margin (F) and fixed costs. Fixed costs can be divided in two groups: the one independent of the maintenance strategy: K_{fa} (\$/year) and the other depending on the maintenance policy: K_{fb} (\$/year).

Both kinds of fixed costs must be referred to the whole period defined by the capacity.

The above approach allows to decide whether minimization of the operation and maintenance costs or the maximization of the availability factor assures the higher profit. The optimum decision criterion is as follows:

$$f \cdot (A_{2,max} - A_1) \left\{ \begin{array}{l} > (c_{0,2} - c_{0,1,min}) \rightarrow \max A \\ < (c_{0,2} - c_{0,1,min}) \rightarrow \min c_0 \end{array} \right\}, \quad (7)$$

where $f = s - k_p$ (\$/h) the specific contribution margin.

Thus, it can be stated that the operation designed for costs minimization is more favourable than the strategy maximizing availability only when the contribution margin increase attainable by the latter strategy is smaller than the growth of operation costs.

5. Final Remarks

It has been unambiguously experienced that technical reliability analysis of production and service systems and set-up of reliability-based maintenance strategies may be only successful if they contribute measurably to production design safety and improvement of production efficiency, in addition to direct advantages provided for maintenance departments.

In this paper we set out to call the attention to the close connection between production design and maintenance design, and to their equal role. The presented maintenance model example as (one system element, flexible strategy) was selected for the better interpretation of our approach. In our experience, the problem examined can be dealt with a similar approach also in the case of more complicated systems and conditions. Thus, during maintenance of a complex equipment, the decision problem outlined here is of practical importance due to interactions of the particular system components and because of the variety of maintenance strategies applied (those with rigid or flexible cycle structure, strategies depending on repair, prevention and state).

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