Dependability Analysis of the Injection Press Using Weibull Distribution

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The aim of this paper is an analysis of dependability of an injection press. Collected data - operating times between failures and times to restoration for a year of the use of the press were processed using the Weibull distribution, for which the following basic steps were applied in compliance with ČSN EN 61649:2009 standard. The output includes Weibull distribution parameters and basic functions of reliability and maintainability, i.e. probability of failure and of reliability, density and intensity of failures, then also probability of restoration and restoration probability density. Last but not least, mean time between failures and mean time to restoration including steady-state availability were calculated. The results obtained can be useful for internal benchmarking in an organization with a higher number of presses and for developing a maintenance strategy.

Keywords: Dependability, Weibull distribution, injection press

1 Introduction

Dependability is a highly significant field not only in technical applications nowadays. During last decades, close attention was paid above all to production quality, while dependability has often been neglected in practice. Application of dependability tools contributes to ensuring dependability of particular products, machines, systems etc. [15, 16].

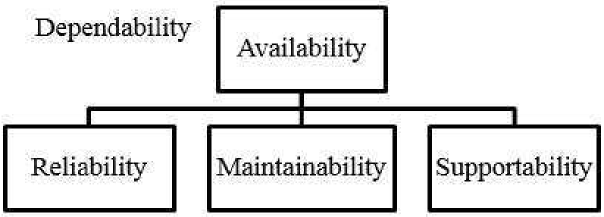

Fig. 1 *Relation between dependability characteristics*

Dependability is defined as an ability to perform as and when required. Dependability includes availability, reliability, maintainability and maintenance supportability and in some cases also other characteristics, such as durability, restorability, safety and security. Dependability is used descriptively as a summary term for an object quality characteristics related to time.

In term of operational dependability of machines and manufacturing equipment, following are the most important characteristics: availability, reliability, maintainability and maintenance supportability Fig. 1 [7, 8, 9, 14, 17].

2 Materials and methods

The data collection of ES 5550/1300DK injection press was performed for the whole 2016 year. The injection press was manufactured in 1996 with clamping force of 1300 tones. Design structure of an injection press - see Fig. 2. A programme was implemented to the injection press, recording times of failure occurrence and times of restoration. Operating times between failures and times to restoration were calculated from these data - Tab.1. Data concerning the press accessories, such as a printer, a manipulation robot, a conveyor and a video-camera were excluded. The acquired input data converted to times in hours are shown in Tab. 1. Table 1 contains the sequence number of each failure and restoration, in the first row is assigned to a failure and restoration number, the second row to Operating Time Between Failures *(OTBF)* and in the third row is associated to time to restoration *(TTR)*. These three rows are repeated in the Table 1 until all measured input data are presented.

The data collected and recomputated to time periods were processed using the Weibull analysis, for which the following basic steps was applied in compliance with ČSN EN 61649:2009 standard [4]:

- Ascending order of the input data
- Bernard's approximation
- Substitution to a modified distribution function F(t)
- Linear regression – a straight line equation
- Calculation of α shape parameter and β scale of the Weibull distribution [2, 11].

- Reliability function $R(OTBF)$

$$\boldsymbol{R(OTBF) = exp\left[\left[-\left(\frac{OTBF}{\beta_f}\right)^{\alpha_f}\right]\right]} \tag{2}$$

- Probability of failure $F(OTBF)$

$$\boldsymbol{F(OTBF) = 1 - exp\left[\left[-\left(\frac{OTBF}{\beta_f}\right)^{\alpha_f}\right]\right]} \tag{3}$$

- Failure rate $\lambda(OTBF)$

$$\boldsymbol{\lambda(OTBF) = \frac{\alpha_f}{\beta_f} \cdot \left(\frac{OTBF}{\beta_f}\right)^{\alpha_f - 1} = \frac{f(OTBF)}{R(OTBF)}} \tag{4}$$

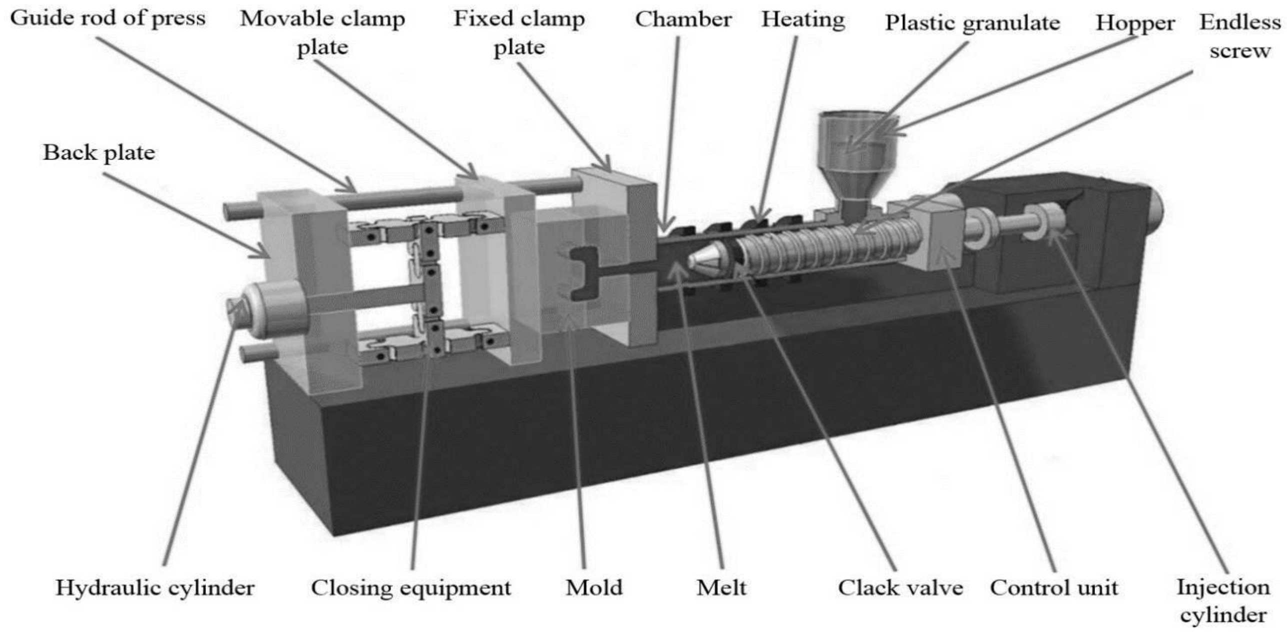

Fig. 2 *Scheme of an injection press*

Tab. 1 *Input data for a calculation of measures of reliability and maintainability including steady-state availability (time periods are given in a format of hours with rounding to two decimal places)*

Failure and restoration no.	1	2	3	4	5	6	7	8	9
Operating time between failures *OTBF* [h]	0.14	0.21	0.47	0.99	1.11	1.11	1.17	1.54	2.01
Time to restoration *TTR* [h]	0.07	0.40	0.57	0.61	0.65	0.73	0.83	0.85	0.99
Failure and restoration no.	10	11	12	13	14	15	16	17	18
Operating time between failures *OTBF* [h]	3.37	4.96	5.11	5.81	8.36	9.60	9.64	11.63	11.66
Time to restoration *TTR* [h]	1.27	1.30	1.31	1.65	1.70	1.77	1.87	1.99	2.00
Failure and restoration no.	19	20	21	22	23	24	25	26	27
Operating time between failures *OTBF* [h]	11.95	12.57	15.30	15.95	18.39	21.28	22.84	29.58	32.09
Time to restoration *TTR* [h]	2.01	2.04	2.14	2.41	2.47	2.85	2.87	2.93	3.08
Failure and restoration no.	28	29	30	31	32	33	34	35	36
Operating time between failures *OTBF* [h]	35.65	36.83	37.59	38.12	41.98	44.57	44.60	46.41	52.31
Time to restoration *TTR* [h]	3.09	3.10	3.15	3.15	3.22	3.37	3.49	3.66	4.22
Failure and restoration no.	37	38	39	40	41	42	43	44	45
Operating time between failures *OTBF* [h]	53.76	54.49	57.57	58.43	62.79	63.64	63.97	64.87	81.06
Time to restoration *TTR* [h]	4.45	4.50	4.80	5.21	5.51	5.72	6.03	6.04	6.08
Failure and restoration no.	46	47	48	49	50	51	52	53	54
Operating time between failures *OTBF* [h]	81.74	91.43	96.42	96.70	97.79	104.53	106.68	108.23	112.52
Time to restoration *TTR* [h]	6.10	6.19	6.41	6.52	7.07	7.19	7.59	7.84	7.85
Failure and restoration no.	55	56	57	58	59	60	61	62	63
Operating time between failures *OTBF* [h]	117.53	121.29	122.53	123.51	130.94	133.56	146.57	149.23	151.44
Time to restoration *TTR* [h]	8.23	9.88	9.88	10.33	10.37	11.43	12.53	13.85	14.42
Failure and restoration no.	64	65	66	67	68	69	70	71	72
Operating time between failures *OTBF* [h]	153.64	155.63	156.05	161.57	163.66	173.29	176.04	177.39	185.35
Time to restoration *TTR* [h]	15.14	15.97	16.73	17.82	18.22	18.86	20.99	21.40	21.83
Failure and restoration no.	73	74	75	76	77	78	79	80	81
Operating time between failures *OTBF* [h]	190.84	221.79	243.70	251.69	271.48	275.76	319.38	326.30	366.65
Time to restoration *TTR* [h]	23.04	24.91	33.83	34.75	39.67	42.83	45.83	55.12	55.94
Failure and restoration no.	82	83	84						
Operating time between failures *OTBF* [h]	372.50	402.59	404.54						
Time to restoration *TTR* [h]	63.21	73.77	–						

To make the picture complete, basic indicators of reliability and maintainability based on the Weibull distribution of operating times between failures and times to restoration, mean times and availability are given as well:

- The Weibull distribution probability density function of operating time between failure

$$\boldsymbol{f(OTBF)} = \frac{\alpha_f}{\beta_f} \cdot (\boldsymbol{OTBF})^{\alpha_f - 1} \cdot \boldsymbol{exp}\left[-\left(\frac{OTBF}{\beta_f}\right)^{\alpha_f}\right] \quad (1)$$

Where:

α_f…Shape parameter of Weibull distribution for operating time between failures [-],

β_f...Scale parameter of Weibull distribution for operating time between failures [-],

OTBF…Operating time between failures [h].

- Estimation of mean operating time between failures *MOTBF*

$$\boldsymbol{MOTBF} = \frac{1}{m} \cdot \sum_{j=1}^{m} \boldsymbol{OTBF_j} \quad (5)$$

Where:

m…Number of failure of repaired object [-],

$OTBF_j$…j^{th} operating time between two consecutive failures (j – 1; j) [h].

- The Weibull distribution probability density function of time to restoration $f(TTR)$

$$\boldsymbol{f(TTR)} = \frac{\alpha_r}{\beta_r} \cdot (\boldsymbol{TTR})^{\alpha_r - 1} \cdot \boldsymbol{exp}\left[-\left(\frac{TTR}{\beta_r}\right)^{\alpha_r}\right] \quad (6)$$

Where:

α_r…Shape parameter of Weibull distribution for time to restoration [-],

β_r...Scale parameter of Weibull distribution for time to restoration [-],

TTR…Time to restoration [h].

- Probability of performing restoration within a given time $M_{pr}(TTR)$

$$\boldsymbol{M_{pr}(TTR)} = \boldsymbol{1 - exp}\left[-\left(\frac{TTR}{\beta_r}\right)^{\alpha_r}\right] \quad (7)$$

- Probability of not performing restoration within a given time $M_{npr}(TTR)$

$$\boldsymbol{M_{npr}(TTR)} = \boldsymbol{exp}\left[-\left(\frac{TTR}{\beta_r}\right)^{\alpha_r}\right] \quad (8)$$

- Estimation of mean time to restoration *MTTR*

$$\boldsymbol{MTTR} = \frac{1}{n} \cdot \sum_{j=1}^{n} \boldsymbol{TTR_j} \quad (9)$$

Where:

n…Number of restorations of repaired object [-],

TTRj…Time to restoration of jth failure [h].

- Steady-state availability *A*

$$\mathbf{A} = \frac{\boldsymbol{MOTBF}}{\boldsymbol{MOTBF+MTTR}} \quad (10)$$

Where:

MOTBF…Mean operating time between failures,

MTTR…Mean time to restoration (contains mean corrective time + time of undetected failure state and administrative delay).

3 Results and discussion

No data concerning dependability of similar injection presses were found in the available literature. Therefore one cannot compare the results achieved with other authors dealing with similar issues.

Using formerly derived relations, values of the Weibull distribution parameters for operating time between failures *OTBF* and time to restoration *TTR* can be calculated (table 2):

Reliability indicators and their function values calculated according to equations (1-5) are shown in Fig. 3 and maintainability indicators calculated according to equations (6-10) are shown in Fig. 4.

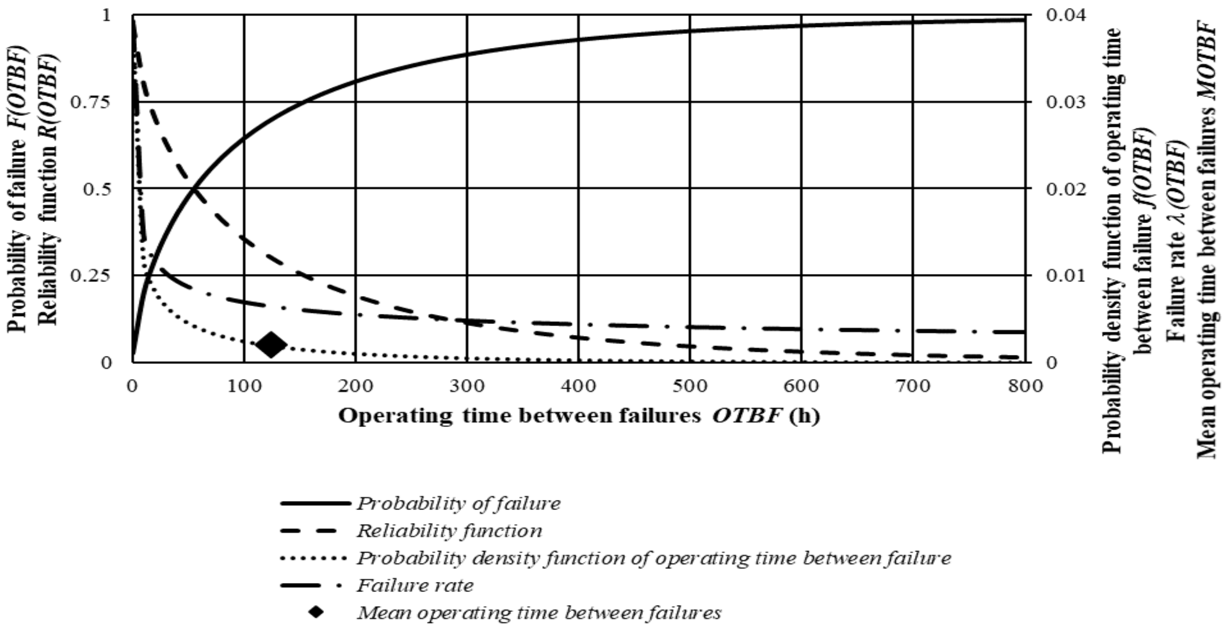

Fig. 3 *Dependability measures depending on operating time between failures*

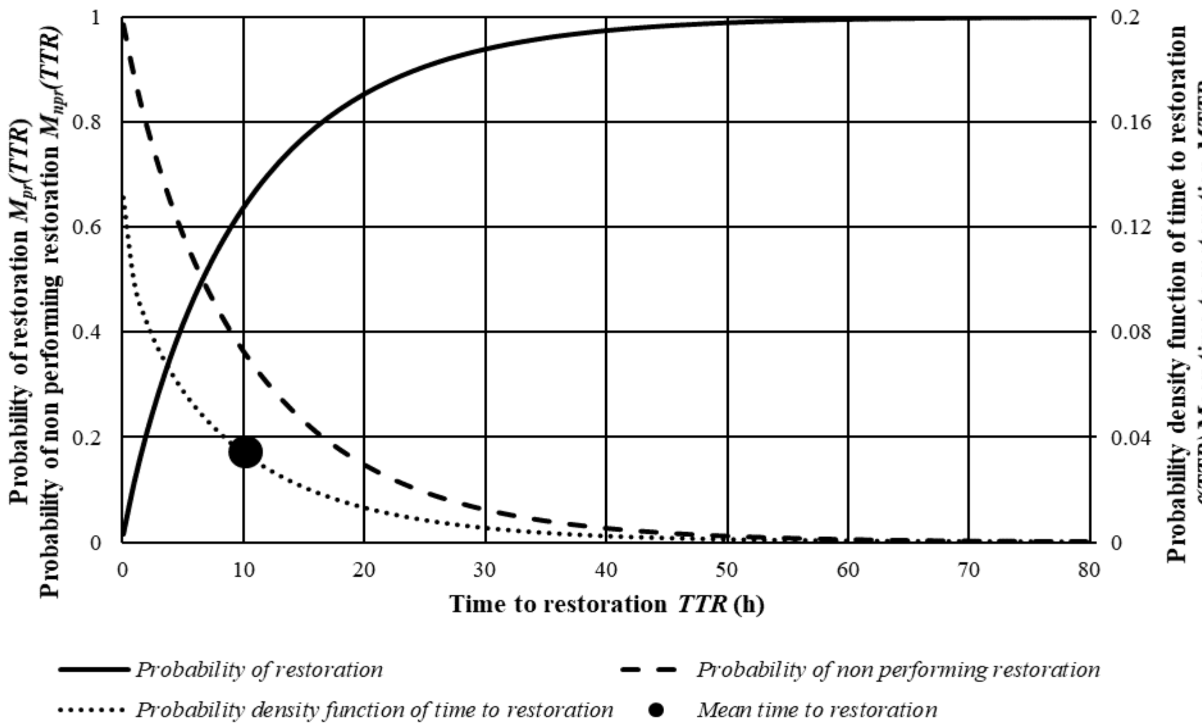

Fig. 4 *Maintainability measures depending on time to restoration*

Tab. 2 *Weibull distribution parameters, indicators of reliability, maintainability and availability*

Parameter/indicator	α shape parameter	β scale parameter	*MOTBF* [h]	*MTTR* [h]	*A*
reliability	0.674	94.83	124.55	--	0.924
maintainability	0.923	9.90	--	10.27	

4 Conclusions

The acquired reliability and maintainability measures of the injection press can be used for application of restoration theory when deciding on applicability of preventive maintenance or corrective maintenance, creating a maintenance plan [1, 3, 5, 6, 8, 10, 12, 18] purchasing a new press, looking for ways to increase the machine effectiveness through availability enhancement [7].

Long-term monitoring of dependability data can also be used for assessment of production equipment ageing process, for internal objectification of decisions on restoration of a machine as a whole.

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