



Reliability Considerations for Machine Design

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Jyoti Mukherjee, P.E.

Reliability and Probability

Reliability analysis is almost mandatory for any complex machinery and equipment to predict machine behavior during its lifetime use. A discussion on types of data is due herewith. Any event could be deterministic or probabilistic by nature. For example, “sunrises in the east” is a deterministic event, whereas “today it will rain or not” is a probabilistic event since it is not sure to happen. Probabilistic events have uncertainties about the outcome of the event. Reliability is about probabilistic events, such as whether machine life will exceed 200 hours. The reliability and probability of any event are related to each other. The definition of reliability in terms of machine design activities could be as follows:

Reliability of any machine could be defined as the probability of delivering desired performances by the machine during the desired life of the machine when operated under assumed external and internal operating conditions, which could include internal and external forces and environmental conditions. So, by definition, reliability is the prediction of the outcome of a machine event. Generally, reliability is defined around the possibility of success of an event, i.e., whether the event will happen. A machine is deemed reliable when it delivers the desired performances during the desired life of the machine, i.e., the machine will turn on when switched on.

A car is 100% reliable when it starts every time it is turned on without any failure to start. Beyond the expected life of the car, the car may fail to start, i.e., reliability is less than perfect, 100%. Reliability is an essential index of the quality of a machine. Reliability has to be designed in the machine, which is an outcome of a good design process. To enhance the reliability of a machine, an adequately planned reliability requirement has to be assumed, and validation of reliability data for the machine has to be ascertained. Systemic analysis and testing must be completed to determine the machine's reliability. Reliability analysis of the machine for a complex system needs to be performed during the design and analysis phase of the machine development. Moreover, machine system reliability is not the same as component reliability. So, systemic and sub-system analyses need to be considered. The reliability of any system has to be planned and designed in the system.

As mentioned before, components interact to give rise to the system behavior. There is a synchronous effect among components to produce the system behavior or performance. When any component fails during use, the system will fail, but when a component fails, the system might not fail to deliver most of the performances. For example, when a lathe tailstock fails, the machine could still successfully deliver part of the requirements without the tailstock functioning. On the other hand, when the output product of any machine does not satisfy the quality

requirements, the system has failed to deliver the product even if its components have not failed.

System behavior needs to be understood and analyzed as much as possible. System failure and component failures need to be understood properly. Interaction effects among components need to be analyzed. The reliability of components of any machine and the reliability of a machine system are two different things, but they are interrelated. Moreover, a more reliable machine might appear to cost more for the producer initially, but it costs less in the long run. An example of machine failures to determine the reliability is shown below in Table 1.

Example 1:

Number of similar Tool Changer designs running in the field = 1

Useful design Life of each Tool Changer = 5000 hours

Operating Conditions for all machines = Similar

Environmental Conditions of all machines = Similar

Machine Type: Machining Centers, CNC

Make of machines: Same Manufacturer

Table 1: Tool Changer (TC) Failures Vs. Number of operation Hours

Number of hours for TC in the Field, hours	Number of Failures Observed, f_i	Cumulative number of Failures, F_i	Actual Failure Point, hours, X_i
0-500	2	2	268
500-1000	6	8	737
1000-1500	9	17	1207
1500-2000	15	32	1742
2000-2500	19	51	2290
2500-3000	17	68	2767
3000-3500	13	81	3185
3500-4000	10	91	3806
4000-4500	6	97	4307
4500-5000	3	100	4802

Relative Frequency of Failure, Hours

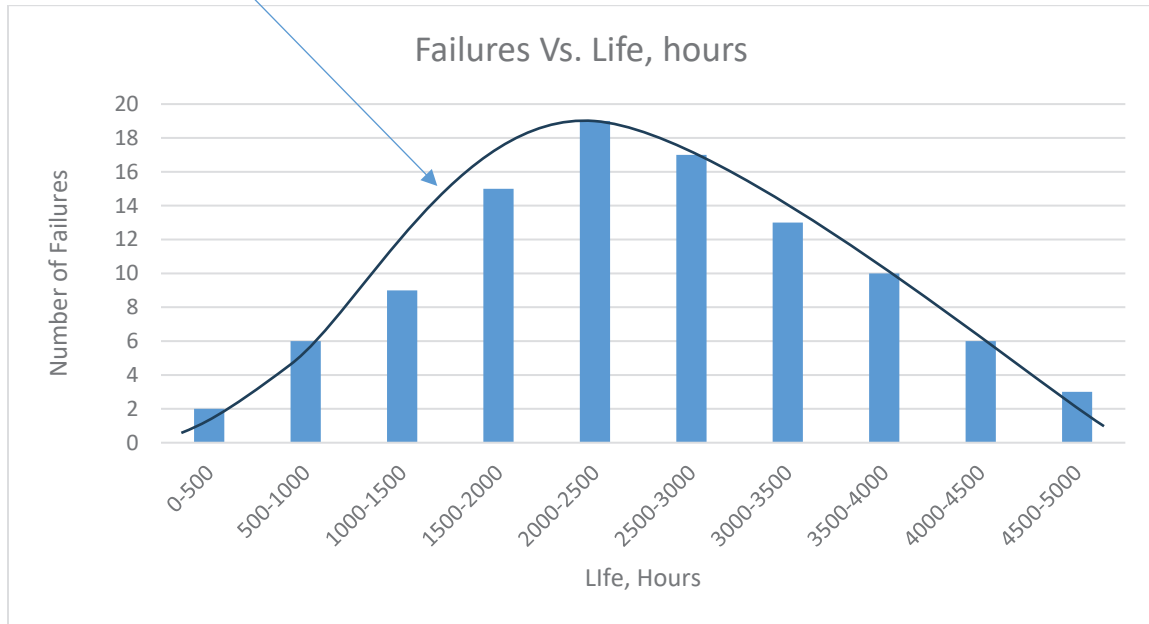


Fig.2. Failures Vs. Life at Failures

Xbar = Average Number of Failures or

$$\begin{aligned}
 &= (1/10) * (\Sigma Xi) \text{ where } 8 \text{ is the number of data points, } n = 10 \\
 &= (268+737+1207+1742+2290+2787+3185+3806+4307+4802)/10 \\
 &= 2511 \text{ hours}
 \end{aligned}$$

$$\begin{aligned}
 \sigma_x &= \text{Standard Deviation of life of Machines} = [1/10 * (\Sigma (Xi - Xbar)^2)]^{0.5} \\
 &= [1/10 * ((268-3139)^2 + \dots + (4802-3139)^2)]^{0.5} \\
 &= 1586 \text{ hours}
 \end{aligned}$$

Note: The average number of failures is much less than the expected design life for the tool changer.

$$\text{Range of Life} = \text{Maximum Life} - \text{Minimum Life, hours} = 4802 - 268 = 4534 \text{ hours}$$

Note: When the range is very high, the standard deviation remains very high, too. It is a measure of the variability of data points.

Median: There are even several data sets, n = 10. Hence, the median is halfway between data points 5 and 6, i.e. (2290+2767)/2 = 2528.5 hours. For an odd number of data points, the middle data point is the median of the data points.

Variance, $s^2 = [(\sum(X_i - \bar{X})^2)] / (n-1) = 2790$ hours

Coefficient of Variation = $C = 100 (\sigma_x / \bar{X}) = 100 * (1586 / 2511) = 63.1$ hours

Probability of Failures between 0 and 2000 hours = $(2+6+9+15)/100 = 0.32$, i.e., there is a 32% chance that the unit will fail between zero and 200 hours of operation, and there is a probability of $(1-0.32) = 0.68$ or 68% that the unit will survive beyond 2000 hours. So, the reliability of the equipment is 68% up to 2000 hours.

Example 2: A turning machine produces 500 machines in one shift. After the production was completed, it was found out that the automatic gaging unit was not working for part of the time. From previous experience, it could be said that 10% of units are beyond the specifications of diameter higher than 2 inches, which is unacceptable. 100% inspection of all the 500 units is time-consuming and costly. The inspector selected 2 units at random for inspection and never remixed them with total production. Assuming the variable Z, what is the probability of finding zero, 1, and 2 out of the selected units for inspection?

Solution: Now, probability of $p_z(0)$ = probability of finding zero defective unit out of three selected units = $p(Z=0) = (\text{number of non-defective units} / \text{total number of production}) \times ((\text{number of non-defective units} - \text{first selected unit}) / (\text{total number of production} - \text{first selected unit})) = ((450) / 500) \times ((450-1) / (500-1)) = 450/500 \times 449/499 = 0.9 \times 0.899 = 0.8091$; so, probability of finding zero defects out of first selection = 0.8091

$p_z(1)$ = probability of finding one defective unit out of 2 units for selection = $(450/500) \times 50/499 + (450/500) \times 50/499 = 2 * 0.9 * 0.1 = 0.1898$

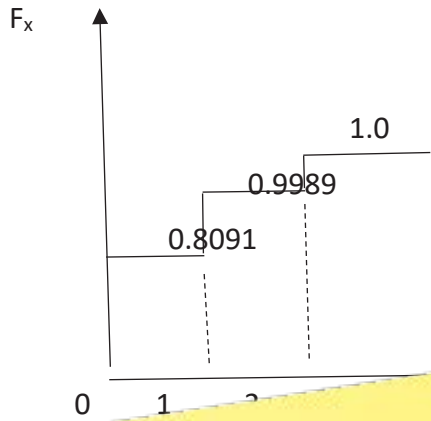
$p_z(2)$ = probability of finding two defective units out of 2 units for selection = $(50/500) \times 49/499 = 0.1 * 0.098 = 0.0098$

The cumulative distribution function, $F(X)$ for the defects are as follows:

$F_x(0) = P(x \leq 0) = 0.8091$

$F_x(1) = P(x \leq 1) = p_x(0) + p_x(1) = 0.8091 + 0.1898 = 0.9989$

$F_x(2) = P(x \leq 2) = p_x(0) + p_x(1) + p_x(2) = 0.8091 + 0.1898 + 0.0098 = 1.0$



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relative value upto x_1

x

Fig.3: Distribution Function for Continuous Variable,