International Journal of Emerging Engineering Research and Technology
Volume. 2, Issue 2, May 2014, PP 64-70

Reliability Analysis of Pressure Relief Valve Manufacturing System

Abhijit S. Adadande[1], A. M. Naniwadekar[2], Rajkumar B. Patil[3]

[1,2,3]Department of Mechanical Engineering, Dr. J. J. Magdum College of Engineering, Jaysingpur, India

Abstract: *To manufacture reliable products, system reliability should be maintained over the time. Hence it is required to design reliable manufacturing system. In proposed work pressure relief valve manufacturing system is selected for analysis. This valve is used in two wheeler bikes having capacity 150CC and above. To carry out this study, large literature survey is carried out. Based on this survey, work objectives are decided and analysis methodologies are selected. It is found that fault tree analysis method is effective in such fault oriented analysis. Weibull++ software has been used for time to failure data analysis. Statistical data is analyzed by Normal distribution model. Focus is on event or faults instead of reliability of each components. System reliability and critical events are found out.*

Keywords: *Reliability, fault tree analysis, Normal distribution, Weibull distribution*

1. Introduction

Industrial manufacturing system consists of few to large number machines. Each machine consists of large number of sub-systems and each sub-system consists of large number of components. Analysis of such system is difficult. Also careful analysis is required to avoid diversion. Reliability analysis along with statistical quality control provides valuable solution. Reliability and quality are two inherent properties of any product. Reliability can also be defined as the quality over time [1]. Quality is associated with workmanship and manufacturing. Therefore if a product doesn't work, fails or breaks as soon as you buy or manufacture it, you would consider the product to have poor quality. However if over time parts of a product wear-out or fail before you expect them to then this would be termed poor reliability. The difference therefore between quality and reliability is concerned with time and more specifically product life time.

In case of manufacturing system, a statistical data and quality control methods give primary information about the manufacturing system. Whether the system is reliable or not? If it is reliable, then how much it is. It also gives primary information and area for system reliability improvement. In presented case study, pressure relief valve is selected for analysis. Presently, the rejection rate is around 6% and large amount of rework is required. The prime objective of this study is to understand reasons of rejection of valve manufacturing system. Based on statistical data system reliability will be estimated. Events are separated based on severity.

The work is divided into four phases. In first phase, study of pressure relief valve manufacturing system will be carried out. Problem will be defined. In second phase, fault tree model will developed for estimating system reliability. Thereafter, statistical data is collected and analyzed. Probability of occurrence of each event will be estimated. Finally system reliability will be estimated. Rejection and rework rate will be estimated.

2. Problem Definition

The pressure relief valve is used to remove excess high pressure (pressure rating set by company is 2.6 bar) exhaust gas from engine. It avoids bursting of cylinder. It is also useful for smooth operation of the engine. Requirement of this valve is 1,00,000 per month. It is found that the rework rate is considerable. Even after rework, rejection rate is 6% per month; 6,000 valves get rejected every month. Rejections are due to

1. Geometric dimensions

2. Valve fails to open at desired pressure range

To reduce this rejection, industry needs reliability analysis of the production line as well as to design and develop the methodology to check the pressure (it should be 2.6 bar) at which pressure relief valve will open. To fulfill the requirement of the company, following questions and objectives are formulated.

- What is the rework and rejection rate of pressure relief valve per month?
- What are the reasons of rejection?
- What are the tools and techniques to be implemented to improve system reliability and reducing rework and rejection rate?
- To implement reliability improvement suggestion.
- To analyze statistical data after implementation of improvement suggestions.
- To estimate reliability, rework and rejection rate.
- To compare earlier and improved cost of rework and rejection.

3. PRESENT THEORY AND PRACTICES

To fulfill the requirement, it is required to carry out extensive literature survey. It will give present theories and practices. What are the tools, techniques and methodologies are presently in use for the reliability analysis of manufacturing system. What are the different techniques suitable for the development of pressure relief valve testing methodology? Large numbers of books, handbooks, national and international papers have been collected and studied. Some of the finding and analogical study are as discussed here.

Kumar [2] carried out reliability analysis of piston manufacturing system. Analysis has been carried out by fault tree analysis method. Objective of the analysis was to reduce system downtime as well as improve quality of the piston to minimize rejection percentage. Improvement methods are suggested in order to improve reliability of the system.

Sheng-Hsien (Gary) Teng and Shin-Yann (Michael) Ho emphasized on Quality and reliability of products and manufacturing process are absolutely critical to the manufacturing outcome – functional performance of the final product. To ensure good product quality, an efficient and comprehensive quality system must be established in the very early stage of product design. In order to meet product reliability requirements, reliability analysis must contain both product design and process operations.

Chien [3] has suggested ANOVA method for the analysis of reliability of safety valve. The proposed methodology has focused on failure data collection, grouping of data and analysis is carried out. In this method, a semi-quantitative Reliability based improvement methodology is established which shows a plan, do correct and action (PDCA) loop.

Venter and Scotti [4] suggested a methodology for including the results of proof/acceptance tests in the reliability based design optimization (RBDO) process. The proposed method allows for the simultaneous design of the structural component and the proof test itself and provides the designer with direct control over the probability of failing the proof test. The results indicate that a significant weight saving is possible by including the proof test results in the design process as compared to equivalent deterministic or RBDO designs, while maintaining the same probability of failure as obtained from the deterministic design.

Algin [5] presented a new approach of estimation of reliability of systems. The traditional reliability theory deals with systems consisting of the depersonalized components which are described by the set of reliability indices. The dependent behaviors of elements are the basic problem in machine and other complex systems. The developed approaches and techniques allow producing the real connections between components.

Frank [6] used fault tree analysis (FTA) method to increase the reliability of spacecraft mission namely 'Mars Micro-Met Mission'. The analysis included the functional block diagram framework useful to structure a supporting fault tree analysis. Reliability analysis at an early stage of mission design was shown to be highly effective method for reducing the predicted risk of mission failure. He also suggested that it is better to implement reliability improvement options early in the design when it is least costly to make changes.

Kumar [7] analyzed different systems like lathe machines and printing circuit board assembly using fault tree analysis method and the qualitative and quantitative results have been presented. FTA method was used to estimate reliability of different systems. In manufacturing industry fault tree analysis is used as a diagnostic aid to detect when failure occurs in system. The most difficult part of creating a fault tree is the determination of top level event. The selection of top event is crucial since hazards in the system will not be comprehensive unless the fault trees are drawn for all significant top level events. After that, determining events related to top event which are arranged in logical relation between them by using logical symbols is also important.

3.1. Summary of literature survey:

From extensive literature review, it is found that reliability analysis of pressure relief valve manufacturing process has not done yet. Most of the researchers have selected a single machine or system for analysis. Few of them analyzed reliability of manufacturing system. Reliability analysis of piston manufacturing system and mining equipment's are discussed. Hence reliability of manufacturing system of piston manufacturing system can be carried out using tools and techniques of existing work. Fault tree analysis method is most effective tool in such type of analysis. Statistical data of valve can also be used for finding critical sub-systems.

4. DEVELOPMENT OF PROCESS FLOW DIAGRAM FOR MANUFACTURING SYSTEM

Process flow diagram is developed to understand manufacturing system of pressure relief valve. For the construction of same detailed study of manufacturing system is carried out. Process flow diagram is useful for the construction fault tree diagram. Trob, CNC, Slotting, and drilling machine are used for different operations. First of all, bar is cut at required length and then it is forwarded for further operations such as facing, threading, drilling, slotting etc. Figure 4.1 shows detailed process flow chart of manufacturing system. Trob machines are used for Facing and combined drilling operations. Threading, Circlip groove turning and facing for total height are carried out on CNC machine. Thereafter slotting operation is performed. After each machining operation, quality inspection is carried out. Then, valve is assembled. Assembled valve is tested on developed pneumatic testing methodology. Finally, Packing and dispatching will be carried out. Rework and rejection decision is taken at inspection & quality control stage and after testing if necessary.

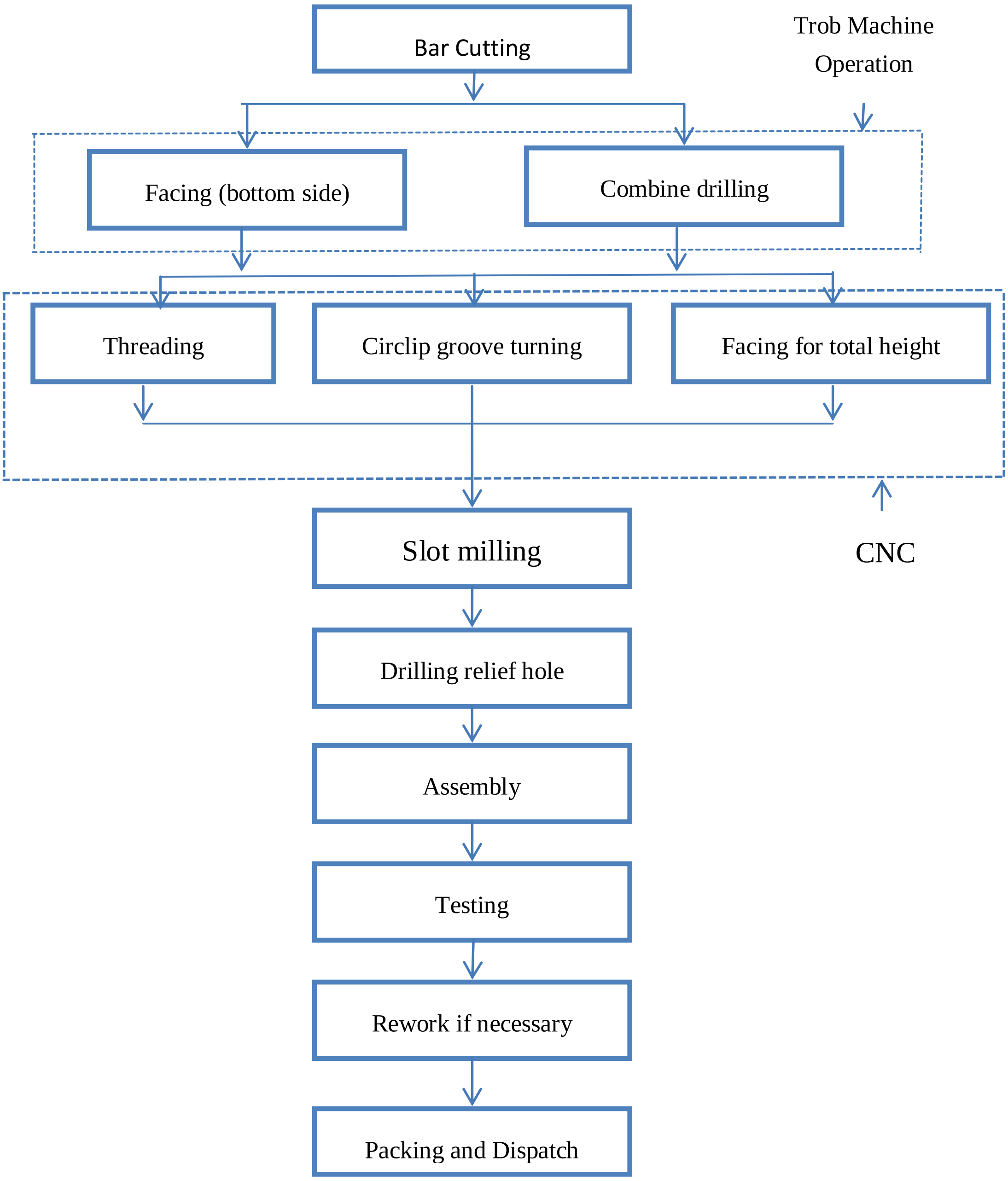

Figure 4.1. *Process flow diagram of pressure relief valve manufacturing system*

5. Fault Tree Construction and Model Development

Fault tree diagram is constructed by using faults and reasons of failure data. The data is collected from testing of pressure relief valve and quality inspection. Fault tree (FT) diagram is presented in APPENDIX I. 'Rejection of valve' is considered as top event. There are total twelve events which are responsible for rejection of the valve. They are (Circlip groove length (21.10 ± 0.1), Length 6.50 ± 0.1, Length 4.60 ±0.20, Total height 23.5 ± 0.1, Groove diameter 10.40 ± 0.11, Diameter 10.10 ± 0.1,Outer diameter valve, Thread, 45^0 Chamfer, Ball, Circlip, Spring.). All the events are incomplete events, hence they are connected with top event using OR gate. It is clear that, occurrence of any event leads to occurrence of top event.

Let the events (Circlip groove length (21.10 ± 0.1), Length 6.50 ± 0.1, Length 4.60 ±0.20, Total height 23.5 ± 0.1, Groove diameter 10.40 ± 0.11, Diameter 10.10 ± 0.1,Outer diameter valve, Thread, 45^0 Chamfer, Ball, Circlip, Spring.) are denoted by X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11} and X_{12}respectively. For qualitative analysis, Boolean algebra method has been used. In this method, '+' sign denotes OR gate and '.' sign denotes AND gate. The derivation of model development is as discussed below.

$$F = X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12} \quad (1)$$

Equation (4.1) gives the relationship between top event and basic events. Probability of occurrence of top event is,

$$P(F) = P(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12})$$

Therefore reliability of the system is,

$$R_s = 1 – P(F)$$
$$R_s = 1 - P(X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 + X_9 + X_{10} + X_{11} + X_{12})$$
$$R_s = 1 – [P(X_1) + P(X_2) + P(X_3) + P(X_4) + P(X_5) + P(X_6) + P(X_7) + P(X_8) + P(X_9) + P(X_{10}) + P(X_{11}) + P(X_{12})]$$
$$R_s = 1 – [(1 – R_1) + (1 – R_2) + (1 – R_3) + (1 – R_4) + (1 – R_5) + (1 – R_6) + (1 – R_7) + (1 – R_8) + (1 – R_9) + (1 – R_{10}) + (1 – R_{11}) + (1 – R_{12})]$$

Let R_1, R_2, R_3, R_4… R_{34} be the reliabilities of the components X_1, X2, X_3… X_{12}.

$$R_s = 1 – [(1 – R_1) + (1 – R_2) + (1 – R_3) + (1 – R_4) + (1 – R_5) + (1 – R_6) + (1 – R_7) + (1 – R_8) + (1 – R_9) + (1 – R_{10}) + (1 – R_{11}) + (1 – R_{12})] \quad (2)$$

Equation 4.2 gives the resultant model for reliability analysis.

6. Reliability Analysis

As discussed, rejection of valve was 6%. Large amount of rework was required to reduce rejection rate. To know exact rejection and rework, statistical data of valve is collected and analyzed. The data is collected before rework activity. Rejection of valve is due to variation in dimensions and specifications of brought out items. Statistical data of all the eleven events are collected and analyzed. Normal distribution is used for data analysis. Table 6.1 shows mean standard deviation, reliability and unreliability of individual event. Reliability and unreliability is expressed in percentage of acceptance and rejection. As all the events are connected by OR gate, system reliability is the product of reliabilities of individual events.

Table6.1. *Mean, Standard Deviation and Reliability*

Sr. No.	Particular	Mean	Standard Deviation	Reliability	Unreliability
01	Circlip groove length (21.10 ± 0.1)	21.0998	0.0348	99.59	0.41
02	Length 6.50 ± 0.1	6.4917	0.0737	82.17	17.83
03	Length 4.60 ±0.20	4.5461	0.0799	96.57	3.43
04	Total height 23.5 ± 0.1	23.5091	0.0297	99.88	0.12
05	Groove diameter 10.40 ± 0.11	10.5064	0.0211	56.75	43.25
06	Diameter 10.10 ± 0.1	10.0678	0.0100	100	00
07	Outer diameter of valve	---	---	100	00
08	Thread	---	---	100	00
09	45° Chamfer	---	---	100	00
10	Ball	---	---	100	00
11	Circlip	---	---	100	00
12	Spring	---	---	100	00
			System =	**44.80**	**55.20**

From reliability analysis, it is found that system reliability is 44.80% and unreliability is 55.20%.Most of the rejection and rework is due to groove diameter, length 6.5mm and length 4.6mm. These are the critical events. It is required to improve the accuracy of the machines used for the above operations. Total rework percentage is,

Rework = Unreliability – Rejection percentage given by company
Rework = 55.20 – 100*0.06
Rework =49.20

6.1. Reliability Analysis based on tool performance

Reliability of pressure relief valve manufacturing system depends on tool wear rate and condition of the system. Hence, after estimation of reliability based on statistical data of pressure relief valve, wear rate of the tools used for manufacturing system are estimated. Total seven tools are used. Table 5.2 shows earlier tool re-sharpening and replacement period.

Table 5.2. *Earlier tool re-sharpening and replacement period*

Sr. No.	Tool used	Operation and particular	Replacement/ Re-sharpening	Period (Jobs)
01	HSS Drill (Combined Drill)	Combined drilling	Re-sharpening	5000 jobs
02	TNMG insert	Turning	Replacement	10000
03	Internal grooving tool(Brazed)	Groove turning	Re-sharpening	5000 jobs
04	End mill	Slot cutting	Replacement	400 jobs
05	Drill	Relief hole	Replacement	500 jobs
06	White bit	Internal turning	Replacement	3000 jobs
07	Thread roll	Threading	Re-sharpening	50000 jobs

From statistical data analysis, it is found that the rejection and the rework start after 50% jobs completed on each machines. Statistical data is analyzed for 50%, 80%, 90% and 95% life of tool. Thereafter the rejection and rework rate is increased and considerable after 90% reliability (job completion).Statistical data is analyzed for 50%, 80%, 90% and 95% reliability. Table 5.3 shows cumulative combined rework and rejection of valves for various time steps.

Table 5.3. *Cumulative combined rework rejection for various time steps*

Sr. No.	Name of the element	Reliability (for different tool life)			
		50%	80%	90%	95%
01	Circlip groove height (21.10 ± 0.1)	100	100	100	98.36
02	Length 6.50 ± 0.1	90.42	87.24	86.31	54.72
03	Length 4.60 ±0.20	100	100	97.37	96.82
04	Total height 23.5 ± 0.1	100	100	100	97.47
05	Groove diameter 10.40 ± 0.11	100	100	100	71.57
06	System	90.42	87.24	84.04	48.54

7. SUMMARY

Following conclusions are drawn from Reliability and cost analysis of pressure relief valve manufacturing system.

- Rejection of the valve is around 6%.
- Rework on pressure relief valve is around 49.20%.
- Reliability of the manufacturing system is 44.80%.
- Most of the rejection and rework is due to groove diameter, length 6.5mm and length 4.6mm. These are the critical events. It is required to improve the accuracy of the machines used for the above operations.

8. SCOPE FOR FUTURE WORK

- ❖ Most of the rejection is due to groove diameter 10.40mm. Separate FTA analysis of CNC machine is required to reduce rejection and rework.
- ❖ Trob machine is used for manufacturing length 6.5mm. Rework is around 17.83%. It is required to carry out reliability analysis of Trob machine.
- ❖ Rework and rejection can be minimized by precise study of tool wear rate.
- ❖ Cost analysis (rejection and rework) can be carried out.

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