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Study on Equipment Failure and Loss Estimation through Taguchi Method with Risk Management

L.Savadamuthu, S.Muthu, S.Gunasekharan

Abstract: ***In the highly competitive business environment, manufacturing organizations are seeking new strategies to improve the quality of product reduce product cost, eliminate loss producing events and reduce wastage arising out of manufacturing system, and the cited subjects are aggressively discussed in the present days. Processing equipments are playing important role in achieving the high quality product and productivity in manufacturing organizations. The equipment failures may occur on various accounts during the manufacturing process. The cost of special and sophisticated manufacturing equipment are high and their idle time or down time becomes more expensive. Hence the effective maintenance system is most important for better utilization of resources. A case study has been taken up from preventive maintenance department at M/s Premier Instruments and Control Limited (PRICOL) to develop effective maintenance system. One of the risk management techniques has been used to predict the probability of occurrence and severity of failure events for prioritizing the risk. In identifying the root causes of the failure, the common tools like fault tree analysis is made use of. The losses due to risks are computed using Tauguchi method. Further evaluated and risk control measures like reduction, risk avoidance, risk transfer and risk retention are effected on critical failure events.***

Key words- Failures, FTA, Risk Management,Taguchi Loss Function

I.INTRODUCTION

In the pursuit of excellence, organizations are in search of new methods and technologies to attain high quality product with reduced product costs through effective control of loss producing events. The manufacturing organizations consist of many risks to human operator, physical facilities, equipment and environment. These will result in product quality, production interruption and accidents. Researchers analyses machine failure and reveal that it would disturb automated production processes and also causes accidents(Thomas Backstrom,1997).In this thesis, a case study on plastic injection molding machine is selected because of it lead to frequent failure events in the process system. The injection molding machine is used in production of automotive components which are of thermoplastic materials such as polyethylene, flexible polyvinyl chloride, ABS resin etc. An analysis on equipment is done to predict the probability of failure events and severity on the process system. There are number of risk management tools to assess the loss producing events, however fault tree analysis (FTA) is considered to be an effective tool as it imbibes all the activities. The data on failures of the injection molding machine for a period of twelve months are collected and analyzed.

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II. LITERATURE REVIEW

Literature review is considered as first step to identify and justify the topic of the study and analysis. It help to develop a better understanding of a problem area and extend to which work has been done in the area. The numbers of papers from various authors were referred for identifying the researchers contribution to maintenance activities through risk management techniques. Joanna.C Bennet et al.(1996) – Describes the risk and risk analysis techniques to software safety assessment is included together with an outline of the methods currently being used to detect software faults[6]. Faisel khan et al., (1998) – Presents a state of art review of the available techniques and methodologies for carrying out risk analysis in process industries such as Hazard and Operability method (HAZOP),.Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis(FMEA) [4]. Sharratt P N et al (2002) – Describes that chemical and related process industries are particularly exposed to environmentally related costs arising from normal operation and accidents, not only of their own processes but also other processes in their supply chain. A methodology is presented for assessment of all such risks due to design of new processes [10]. Robert et al (1982) – Risk management is the process minimization of adverse effect on the organization due to the presence of pure and speculative risks inherent in the manufacturing activities [3]. Lynne P Cooper (2003) – Presents a practitioner view of the desired characteristics of tools to support new product development and suggests research agenda for the use of knowledge based tools from the perspective of balancing benefits and risks [7].

III. PROBLEM DEFINITION

The various authors recommended that the risk management techniques and methodologies are effective tool to predict losses based on the probability of occurrence frequency and severity of risks in different fields such as nuclear, chemical, space and network projects. From the literature survey it is seen that however, the maintenance activity is attempted to reduce the loss producing event. Hence it is necessary to attempt, develop and implement risk management technique in maintenance

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field and to prevent the losses to manufacturing industries.

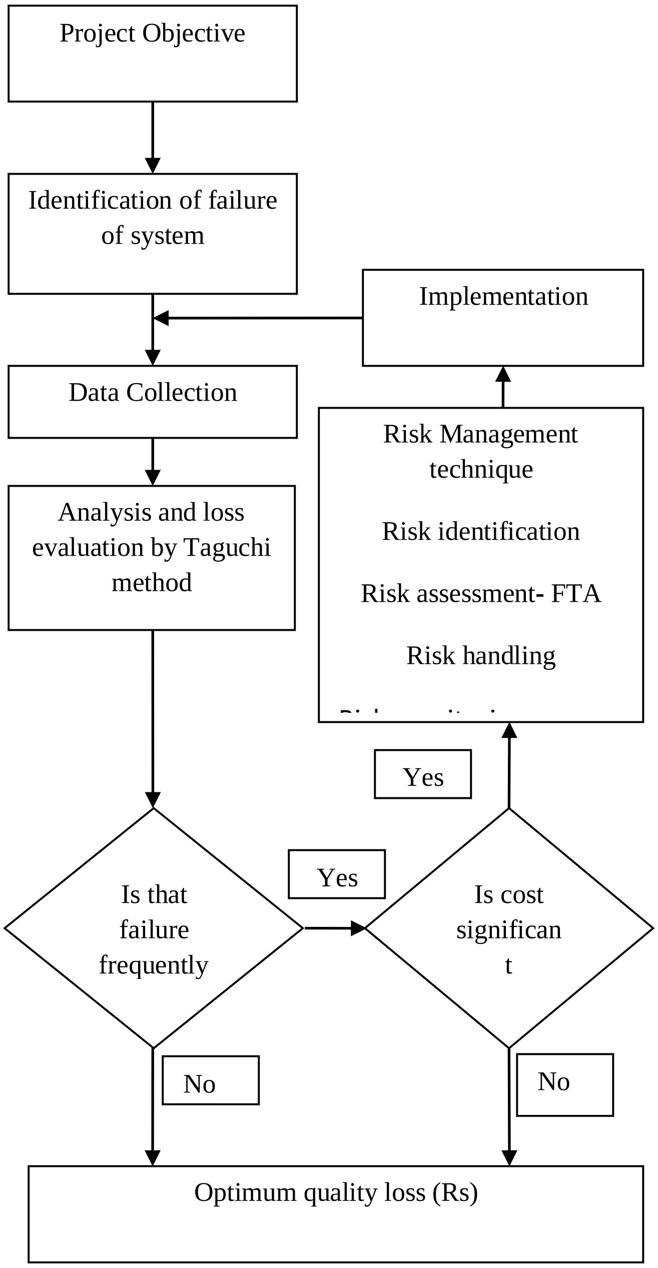
III.1 PROJECT OBJECTIVES

To minimize the number of breakdowns or idle time of process equipment.

To reduce the product cost and improve product quality through effective control of loss producing events.To reduce the running cost of equipment per unit time.

To provide the accurate risk management record for implementation of various system.

III.2 METHODOLOGY



IV. IDENTIFICATION OF FAILURE AREA IN PRODUCTION SYSTEM

The data on availability and idle time (Hours) of the equipment of various manufacturing system are collected from the equipment maintenance record discussion with experts of different departments and conducting a brain storming session in preventive maintenance department at PRICOL. The detailed data on percentage of availability and idle time of manufacturing facilities are computed and recorded as shown (Table 4.1).

SI. NO.	Manufacturing system	Idle Time-(Hrs)	Total Available time(Hrs)	Availability time (%)	Idle Time (%)
1.	P & S 1,2,7	5520.15	5786144	99.9	0.1
2.	P & S 6	869.47	532032	99.8	0.2
3.	M/c shop, printing, P & S 5	1722.40	1847100	99.9	0.1
4.	PCMS 1 & 2	1620.20	1691200	99.9	0.1
5.	Plant III	891.00	2094833	99.96	0.04
6.	Plant IV	1069.10	1354320	99.9	0.1

P & S – Production and supply

PCMS – Plastic component manufacturing system

On discussion with the experts and shop floor practicing engineers, has been opined that PCMS is a critical one, and needs through study as other units performance are depending on it. The Plastic components are manufactured by means of injection molding process.

IV.1 WORKING OF INJECTION MOLDING MACHINE

Plastic injection molding is one of the most important industrial processes in the mass production of plastic goods. General arrangement of the injection moldings machine is shown (Fig 4.1). A feed hopper is filled with thermoplastic raw material in the form of granules or pellets. The pellets or granules are fed into a heater cylinder. Thermoplastic granules are melted to require temperature and melt is forced into a die cavity by reciprocating and rotating screw mechanism. After the part is sufficiently cooled, the molds are opened the part is ejected. Then the molds are closed and the process is repeated automatically.

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Fig. 4.1 Injection Molding

The unwanted portions like sprue, riser and flash are trimmed to get the finished product. An injection molding is a high-rate production process, tool making cost are very high and good dimensional finish in single stroke. Hence it is necessary to utilize the equipment throughout time without failures.

V. EVALUATION OF LOSS BY TAGUCHI METHOD

Taguchi developed number of mathematical methods to replace the existing statistical equation and calculations and all of them find their origin from his simplest model named as quality loss function. In this study, an injection molding machine is selected and their loss is evaluated.

V.1 DATA COLLECTION

The Analyzer is faced with one of the most problem of obtaining or gathering the decided information or data. Utmost care is exercised while collecting data because data constitute the foundation of analysis. The result obtained from the analysis are inaccurate and inadequate the whole analysis may be faulty and the decision taken misleading. Data is obtained either primary or secondary source. Data are obtained either primary or secondary source. Data are obtained on the various failure events of plastic injection molding machine through conducting interview, brain storming, discussion, questionnaire etc., the following necessary data like description of failure events, failure start and finish time, spares used, spare cost, repair cost etc., are collected.

Type of Equipment : Injection Molding machine
Data Period : 01-01-2010 to 31-12-2011
Failure Order number : Failure serial number
Types of Failures : Failure Description
Failure Start Time : Time at which failure occurred
Failure Finish Time : Time at which Failure rectified
Failure Cost : Labor cost, spare cost, Machine hour cost.

V.2 STUDY AND ANALYSIS OF DATA

Data analysis involves summarizing the collected data and organizing in a manner that yiELDS ANSWER TO THE QUESTION. The collected failure data of the injection molding machine are analyzed and are classified into six critical risk producing events as detailed in table. The identified risks are measured for their potential loss and impact of severity. The high potential risks are summarized.

Cost figure in the table indicates the total cost of repair cost spares cost and cost due to loss of production. An amount of Rs.344.00 is accounted for loss of production per hour per hour with the help of estimator of the organization. In addition to that overhead expenses and miscellaneous expenses are accounted in this analysis.

Mean time between failure (MTBF) was calculated from the following :

MTBF: (Total available time – Idle time) / Number of failures

Table :5.1 Critical failure events

Sl. No	Description of failure	Freque ncy	Down time (min)	Cost (Rs.)	MTBF (min)
1	Failure of Air compressor system	7	206	6722	6142 3
2	Failure of thermo-plastics material flow system	5	180	3772	8617 1
3	Failure of cooling water circulation system	4	225	5353	1075 95
4	Failure of Oil flow system	4	165	6261	1075 25
5	Failure of mold open/close mechanism	7	400	7567	6138 7
6	Failure of heating system	27	1780	5031 5	1344 4
Total		59	2956	7999 6	

Breakup of the heater failure cost is shown below:
Maintenance and spare cost = Rs. 5041.67
Production loss = Rs.10203.33
Overhead (200% of above cost) = Rs.30494.00
Total cost = Rs. 45741.00
Miscellanous expenses (10% of total cost) = Rs. 4574.00
Total Failure = Rs. 50315.00

The six classified risk and their downtime are used to construct the bar chart are shown in (fig) for easy understanding of the downtime occurred for each failures.

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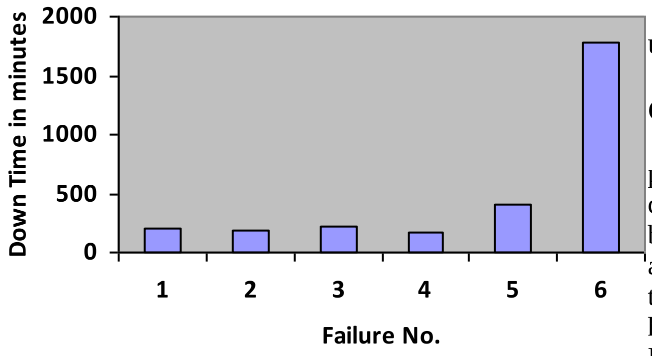
Fig 5.1 FAILURE vs DOWN TIME



V.3 EVALUATION OF QUALTIY LOSS BY TAGUCHI METHOD

In manufacturing organization, they are many factors that affect the quality of the product during production. One of these factors is the production equipment itself. The equipment accuracy and breakdown rate may directly affect the product quality, therefore the necessary preventive maintenance is required to control the equipment failure. Dr. Genichi Taguchi insisted preventive maintenance to control the unnecessary equipment breakdown.

V.3.1 TAGUCHI LOSS FUNCTION

Quality loss function equation was developed by Dr. Genichi Taguchi(1989) is an international consultant in the field of quality control and assurance. Loss function employs preventive maintenance schedule to improve the quality of products and manufacturing systems. He also introduced optimal preventive maintenance schedules that minimize quality loss per hour of manufacturing system. The excessive preventive maintenance results in unnecessary repair and maintenance cost. Therefore an optimal preventive maintenance is schedule the minimize the total cost of repair and down time of equipment.

The schedules can be applied when parameters of production equipment deviates from the target values. Taguchi equation for quality loss function (Loss can be termed in Rupees)

Quality Loss per unit time

$$L = \frac{B}{n_0} + \frac{C}{u_0} + \frac{C^*}{u^*} x \frac{1}{(\Delta)^2} \left[\frac{(\Delta)^2}{3} + \left(\frac{n}{2} + l \right) \frac{(\Delta)^2}{u} \right]$$

Where

$\Delta *$ = Functional limit of a parameter of the production equipment

C* = Loss per failure due to deviations greater than $\Delta *$

U*= Mean Time Between Failure (MTBF)

N= Checking interval

B= Checking cost

Δ = Preventive maintenance limit

C= Preventive maintenance cost

U= Average Preventive maintenance interval

I= Time lag

n_0= Current checking interval

Δ_0= Current maintenance limit

u_0= Current average preventive maintenance interval

CASE STUDY

Taguchi loss function is used to compute the quality loss per running unit time of the injection molding machine. The data for the above parameters are collected and summarized below. The equipment was in operation for six days in a week and twenty four in a day and fifty weeks in a year and therefore the expected machine operating time was 7200 hours per year.

MTBF of the heating system = (432000 – 1780) / (32 ×60)

= 224 Hours

$$= \frac{9}{8} + \frac{473}{1800} + \frac{1572}{224} + \frac{1}{400} \left[\frac{15^2}{3} + \left(\frac{8}{2} + 0 \right) \frac{15^2}{1800} \right]$$

= 1.13+0.26+1.32+0.009

Rs.2.72 [Loss per unit hour]

The quality loss per unit hour running time of the injection molding machine is Rs2.72. This loss is to be reduced with the application of Risk Management Technique.

VI. RISK MANAGEMENT PROCESS

Risk management is the process of minimization of reducing loss producing events due to presence of risk in the system or process. The loss producing event is to be eliminated or reduced to operate the system efficiently and effectively without downtime. Generally, it aims to protect assets, environment and public from loss producing events. The Risk Management is imperative.

To control and reduce risks to the acceptable levels

To reduce the uncertainty in decision making

To increase the public credibility of risk management decision

VI.1 RISK IDENTIFICATION

Risk identification involves identifying all loss producing events that may significantly affect the system or process. Risk may ranges from high impact and high probability to low impact and low probability.

VI.2 RISK ASSESMENT

The objective of risk assessment is to analyze the identified risks which are most critical among them and can be controlled. Attaining to all identified risk is hectic task; hence the measuring and fixing priority of risk is an important factor.

VI.2.1 RISK RATING SCALE

Risk ratings are an identification

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of the potential impact of risks on a program. The identified potential risks are examining and rank of them according to their consequences and probability of occurrence category.

VI.2.2. RATING SCALE FOR CONCEQUECE CATEGORY

The assignment of rating scale for consequence category is to consider the cost impact of each risk. The impact of each risk is further classified into various levels such as very low, minimal, medium, critical and very critical catastrophe and the related weights are 1,2,3,4,5,6 which are shown in table.

Table 6.1 Consequence Categories and Weightages

Category	Weight	Description	Cost Effect (Rs.)
A	6	Catastrophe	Above 25000
B	5	Very Critical	>20000≤25000
C	4	Critical	>15000≤20000
D	3	Medium	>10000≤15000
E	2	Minimal	>5000≤10000
F	1	Very low	≤5000

VI.2.3 RATING SCALE FOR PROBABILITY OCCURRENCE

In this case the assignment of rating scale is to consider the occurrence probability of each risk. The various levels of occurrence probability is further classified which are highly unlikely, rare, low likely hood, can happen, probable, regular and its related weights are 1,2,3,4,5,6 as shown in table

Table 6.2 Probability of occurrence Categories and Weightages

Category	Weight	Description	Probability of occurrence
G	6	Regular	>0.5
H	5	Probable	>0.4≤0.5
I	4	Can Happen	>0.3≤0.4
J	3	Low likelihood	>0.2≤0.3
K	2	Rare	>0.1≤0.2
L	1	Highly unlikely	≤0.1

VI.2.4 RISK MATRIX

The risk matrix represents the probability of occurrence levels weights in columns and consequences weights in rows. Also the matrix is indicated as the acceptable and non-acceptable risk region which are shown in table

Table 6.3 Risk Matrix

	Probability level and weightage						
	L	K	J	I	H	G	
	1	2	3	4	5	6	
Consequence level & Weightage	A	6					Not acceptable failure
	B	5					
	C	4					
	D	3					
	E	2					
	F	1					
			Acceptable failure				

Different types of risk assessment methods are available, but which has varying degree of complexity, cost applicability. Some of these are

- Failure mode effective analysis
- Fault tree analysis
- Event tree analysis
- Cause and effect diagram

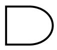
Fault tree analysis is used in our study to identify the basic root causes of loss producing events and corrective measures are effected.

VI.3 FAULT TREE ANALYSIS

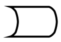
Fault tree analysis and corrective measures are suggested to reduce the failures. The concept of fault tree analysis was originated by Bell Telephone Laboratories in 1962 as s technique to perform a safety evaluation of the Minuteman Intercontinental Ballistic Missile Launch Control System.

VI.3.1 FTA PROCETURE

1. Define the system, and its boundaries and top event.
2. Construct the Fault Tree, which symbolically represented the system and its relevant events.
3. Perform a qualitative evaluation by identifying those combinations of events that will cause the top event.
4. Perform a quantitative evaluation by assigning failure probabilities (or) unavailability's to the basic events and computing the probability of the top event.

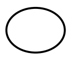


- AND gate: An output event occurs only when all input events have occurred.

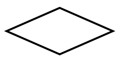


- OR gate : An output event occurs if at least one of the input events has occurred.

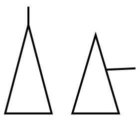
- Resultant Event : A fault event resulting from the logical combination other fault events.



- Basic event : A independent elementary event representing a basic fault.



- Incomplete event : An event has not been fully developed.



- Transfer in and out : Used to link section of the fault tree.

VI.4 CASE STUDY

Study and analysis on the various failure events of injection molding machine in a

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large scale industries is carried out for a period of one year. The machine was in operation for six days in a week, twenty four hours in a day and fifty weeks per year and the expected machine operating time was 7200 hours. During the study the number of failures are observed and grouped into six critical failure events. The identified failures were measured for their potential loss depending on severity and the probability of occurrence.

VI.5 IDENTIFIED CRITICAL FAILURE EVENTS

The identified failures are grouped into six categories and their details are given in Table 6.4

Table 6.4 Identified Critical Failure Events

Sl. No.	Description of Failure	Freq.	Down Time (min)	Cost (Rs.)	MTBF (minutes)	Probability of occurrence
01	Failure of air compressor system	07	206	6722.00	61423	0.07
02	Failure of thermo plastic material flow system	05	180	3772.00	86171	0.06
03	Failure of cooling water circulation system	04	225	5353.00	107595	0.08
04	Failure of oil flow system	04	165	6261.00	107525	0.08
05	Failure of mold open/close mechanism	07	400	7567.00	61387	0.13
06	Failure of heating system	27	1780	50315.00	13444	0.60
Total		59	2956	79996		1.00

VI.6 RISK ASSESMENTS

The severity levels of the above failures (cost impact) are assessed by giving weightage to each failure on consequences. Consequences of failures is categorized into six levels such as A,B,C,D &F with weightage of 6,5,4,3,2 & 1 and the severity ranges from catastrophe, very critical, critical, medium, minimal and very low. The details are shown in `table

Table 6.5 Risk Consequence Categories & Weightages assignment

Sl.No.	Risk	Description (Based on cost effect)	Cost (Rs)	Category/ Weightage
1	Failure of compressed Air flow system	Minimal	6722	E/2
2	Failure of thermo plastic material flow system	Very low	3772	F/1
3	Failure of cooling water circulation system	Minimal	5353	E/2
4	Failure of oil flow system	Minimal	6261	E/2
5	Failure of mold open/close mechanism	Minimal	7567	E/2
6	Failure of heating system	Catastrophe	50315	A/6

Probability of occurrence of each failure is also categorized into six levels such as G, H, I, J, K &L and weightage is given to each level 6, 5,4,3,2 &1 and probability occurrence level ranges from regular, probable, can happen, low likelihood, rare and highly unlikely. The details are shown in Table.

Table 6.6 Probability of occurrence Categories & Weightage assignment

Sl. No.	Risk	Freq.	Description (Based on cost effect)	Cost (Rs)	Category/ Weitage
1	Failure of compressed Air flow system	7	Highly Unlikely	6722	E/2
2	Failure of thermo plastic material flow system	5	Highly Unlikely	3772	F/1
3	Failure of cooling water circulation system	4	Highly Unlikely	5353	E/2
4	Failure of oil flow system	4	Highly Unlikely	6261	E/2
5	Failure of mold open/close mechanism	7	Rare	7567	E/2
6	Failure of heating system	27	Regular	50315	A/6

The identified failures are located in the Risk Matrix based on given weightages according their consequence and probability of occurrence as shown in the table.

Risk = Probability of occurrence × Consequence

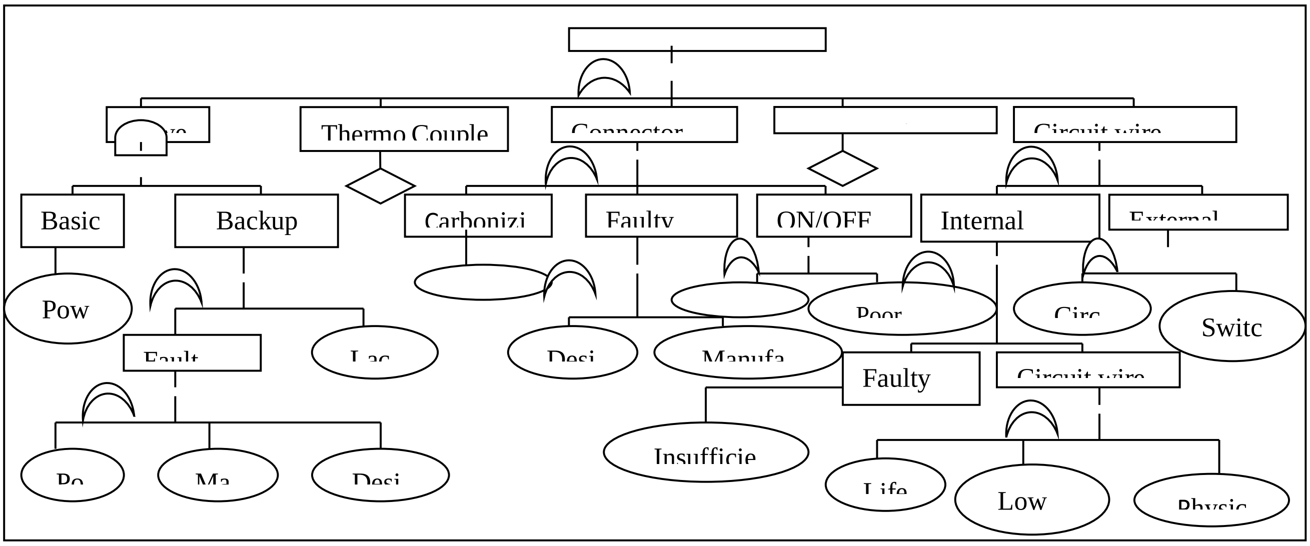

Fig. 6.1 Fault Tree Analysis Diagram of Heating System Failure

Table 6.7 Risk Matrix

			Probability level and weightage						
			L	K	J	I	H	G	
			1	2	3	4	5	6	
Consequence level & Weightage	A	6							Not acceptable failure
	B	5							
	C	4							
	D	3							
	E	2	1, 3, 4	5					
	F	1	2						
				Acceptable failure					

From the matrix table the failure number6, heating system failure is indicated in not acceptable failure region. This failure is required closest attention because it is critical failure event. Therefore the corrective measures are necessary to reduce the critical failure event from non-acceptable level to acceptable level. Hence, it is taken for analysis to identify all the basic root causes with the help of fault tree analysis diagram [fig.6.1] and suitable corrective measures are effected.

VI.7 IMPLMENTATION OF CONTROL MEASURES

Risk identification phase has identified various basic reasons for undesirable risk event with the help of fault tree analysis diagram. Corrective measures are taken to minimize either probability occurrence or cost impact of critical risk event. Due consideration is given to the complexity, cost and applicability of corrective measures before taking any decision. Some of the corrective measures are decided and implemented with expert's opinion.

- Effective maintenance system for heater failure

Fig 6.2 Existing Maintenance system for Heater Failure

- Safety protection for thermocouple
- Optimal maintenance schedule
- Nozzle specification standardization
- Standard temperature controller

Fig 6.3 Existing system for Temperature Control

In PRICOL, preventive maintenance is effected when the control parameter deviates from the target by ±15°C and checked once in every eight hours. From Taguchi Loss Function,
Quality Loss per unit time (L) = Rs.2.70

Dr.Taguchi said, "Using the quality loss function equation and compared the terms first & four and second & third.

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VII. CONCLUSION

Risk Management Program has been developed

to identify possible loss producing events arises in the manufacturing organization. The loss producing events can disturb production process, cause loss of assets and lead to accidents. Risk Management techniques involves identification, assessment and control measures. An injection molding equipment and process are taken for study and analysis. The failure of equipment and process difficulties are collected. The critical failures are analyzed in locating the root causes with the help of fault Tree Analysis. The remedial of the process and injection molding system are compared and the accrued advantages are computed.

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