Evaluation and Reduction of Failure Losses in Production Machines through the Risk Management Approach coupled with the Development of Reactive Maintenance Model

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INTRODUCTION

In competitive scenario, continuous operation of production machines is essential for production of goods at low cost. Failures of machines result in deviation of product quality, production interruption, material damage and accidents (Backstrom and Doos, 1997). Therefore, the processes and failures have to be prioritized and need management's attention. The analysis of failure data is an important facet in the development of management strategy for upkeep of manufacturing system and to optimize the total life cycle cost. In this research work, failures of a solder coating machine are selected for analysis in which an analyzing tool - RMT is chosen to mitigate the failures where as the Taguchi's loss function applied to calculate the losses due to machine failures.

Diagnosis and decision based RMM is developed to analyze the failures of machines. The RMM presented in this paper provides a systematic framework to carry out technical risk assessment to identify the prime causes of machine failures, considering the failure frequency and severity consequences. The model incorporates corrective measure phase with machine enhancement to minimize the failures. The model is of flexible nature in which specific procedures and techniques could be augmented as required by the user. In addition to machine enhancement, the frame work of the model leads to prevention cost and improvements are accepted by looking at the cost benefits and losses. The model uses Taguchi's loss function to estimate the failure losses per unit running time of the machine. The radiator manufacturing organization taken for study, processes high cost materials like copper, brass, tin etc in many special purpose machines. The organization suffers with machine failures and materials wastage significantly that requires process improvements to minimize the losses. Preliminary analysis shows that the contribution of operator failures and material failures are considerable and necessitates the modification of existing Taguchi's loss function to distinguish the material and operator failures from random failures. Necessary corrective measures are taken to reduce the failures and the out come of the implementations was appreciated by the user, shows interest to apply the model for other machines also.

TAGUCHI'S LOSS FUNCTION FOR PM

Machines or processes will have one or more variables that affect the quality of the output product. These variables known as functional parameters are to be controlled to ensure the quality of the out put products. A machine is considered to be failed when it is not able to produce components at the agreed quality and under breakdown conditions. Failures of either type can be reduced by employing PM activities as it helps to maintain the functional parameter of the machine with in the allowable limits (Taguchi et al, 1989). PM involves inspection, repairs and replacement of parts in machine to avoid unexpected failures during their use. Taguchi's loss function is primarily used to estimate the loss due to deviation of functional parameter of the machine or process. Taguchi's loss function equation applied to calculate the loss is given in equation 1, accounts failures costs, PM cost and functional parameter measurement cost.

$$L = \frac{B}{n_o} + \frac{C}{u_o} + \frac{C^*}{u^*} \times \frac{1}{(\Delta^*)^2} \left(\frac{\Delta^2}{3} + \left\{ \frac{n_o}{2} + \zeta \right\} \frac{\Delta^2}{u_o} \right) \quad \ldots\ldots(1)$$

where, L is the loss in Indian rupees per hour of machine running; B (Checking cost): functional parameter measurement cost; n_o(Checking interval): time between two successive measurement processes; Δ (PM limit): limit of functional parameter beyond which PM is to be performed; C (PM cost): PM cost incurred when the amount of deviation of functional parameter reaches Δ ; u_o (Current average PM interval): average time between PM activities performed at the deviation of functional parameter beyond Δ; Δ^* (Limit of functional parameter of machine) : limit of functional parameter beyond which the machine breaks down or produces defective product; C^* (Loss per failure due to deviations greater than Δ^*): loss incurred due to failure of equipment, when functional parameter reaches Δ^*; u^* (Average time between machine failure): average time between machine failures; ζ (Time lag) : time taken for measurement process.

The failure cost (C^*) used in the equation 1 accounts for the cost of machine failures and defective products produced by the deviation of functional parameter. The above failures occur due to many factors such as defective raw material, operator errors, improper process conditions and deterioration of the machine. The loss function used in the present form does not indicate the significance and the effect of such factors explicitly. Assessment of such failures is necessary to take appropriate corrective measures to reduce them. The loss function in the present form is modified as given in the equation 2.

$$L = \frac{B}{n_o} + \frac{C}{u_o} + \frac{C^*}{u^*} \times \frac{1}{(\Delta^*)^2} \left(\frac{\Delta^2}{3} + \left\{ \frac{n_o}{2} + \zeta \right\} \frac{\Delta^2}{u_o} \right) + \frac{C_m}{u_m} + \frac{C_l}{u_l} \quad \ldots\ldots.(2)$$

C_m (material failure cost): cost incurred by processing defective material; u_m (material failure interval): mean time between processing of defective material; C_l (Operator failure cost): cost of failure due to operator errors; u_l (operator failure interval): mean time between operator failures. Material failures refer to as wastage of material due to processing of defective material. Processing of defective material not only wastes the processed material but also wastes the consumables, man power and electric power used to operate the machine. The operator failures refer to as those failures that are independent of machine condition, occur due to negligence of operators which normally lead to a defective product due to the deviation of functional parameter. These failures can be avoided by manual adjustment of the functional parameters.

AN OVERVIEW OF RISK MANAGEMENT PROCESS (RMP)

Risk Management Process (RMP) involves systematic application of management policies, procedures and practices to the tasks of establishing the context, identifying, analyzing, evaluating, controlling and monitoring the risk events. Risk is defined as the combination of the probability of an event and its consequences (ISO/ IEC Guide 51). RMP consists of many phases is applied to reduce the risk events in machines or processes and in many business areas (Stripling, 2001; Patterson and Neailey, 2002). Risk identification phase involves systematic use of the collected information to identify loss producing events that significantly affect the machine or process. Many techniques like brainstorming, questionnaires, industry benchmarking, incident investigation, auditing and inspection are used to identify the risk events and possible consequences. Risk assessment phase organizes the collected information to evaluate the quantum of risks. Risks range from high impact and high probability to low impact and low probability. This phase assesses the frequency, consequences and severity of the risk events by estimating the amount of stake and criticality of risk events. The potential impact of risk events are evaluated by giving weightings to their frequency and consequence. Risk controlling phase identifies and implements necessary corrective measures to reduce the risk to an acceptable level. This phase applies one of the strategies like risk reduction, risk sharing, risk retention and risk avoidance to control the risk events. Risk reduction strategy involves taking necessary corrective measures to lessen the likelihood, negative consequences or both, associated with the risk event. Risk sharing strategy makes another party to involve in sharing some part of the risk by mutual agreement. Risk retention strategy accepts the burden of loss or benefit of gain from the particular risk. Risk avoidance strategy executes the decision not to become involved in, or action to withdraw from handling of risk events. Risk monitoring phase systematically tracks and evaluates the effectiveness of risk control action. It is a proactive technique to obtain information on the progress in reducing the risks to acceptable levels. Documentation phase records all the data as a reference for developing and implementing effective maintenance activities. Risk communication involves the exchange or sharing of information about the risk between the decision makers and others. RMP uses Hazard and Operability study (HAZOP), Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Cause-Consequence Analysis (CCA) etc to investigate and to assess the effects of loss producing events (Kirwan, 1998; Tixier et al., 2002). RMTs and methodologies are effective tools to predict losses based on frequency of occurrence and severity of risk events in different fields such as maintenance in nuclear, chemical, space, manufacturing and network projects (Bennett, 1996). From the literature survey it is observed that the maintenance activity may also be considered to reduce loss producing events. Hence, risk reduction approach of the RMP is applied to control the failures.

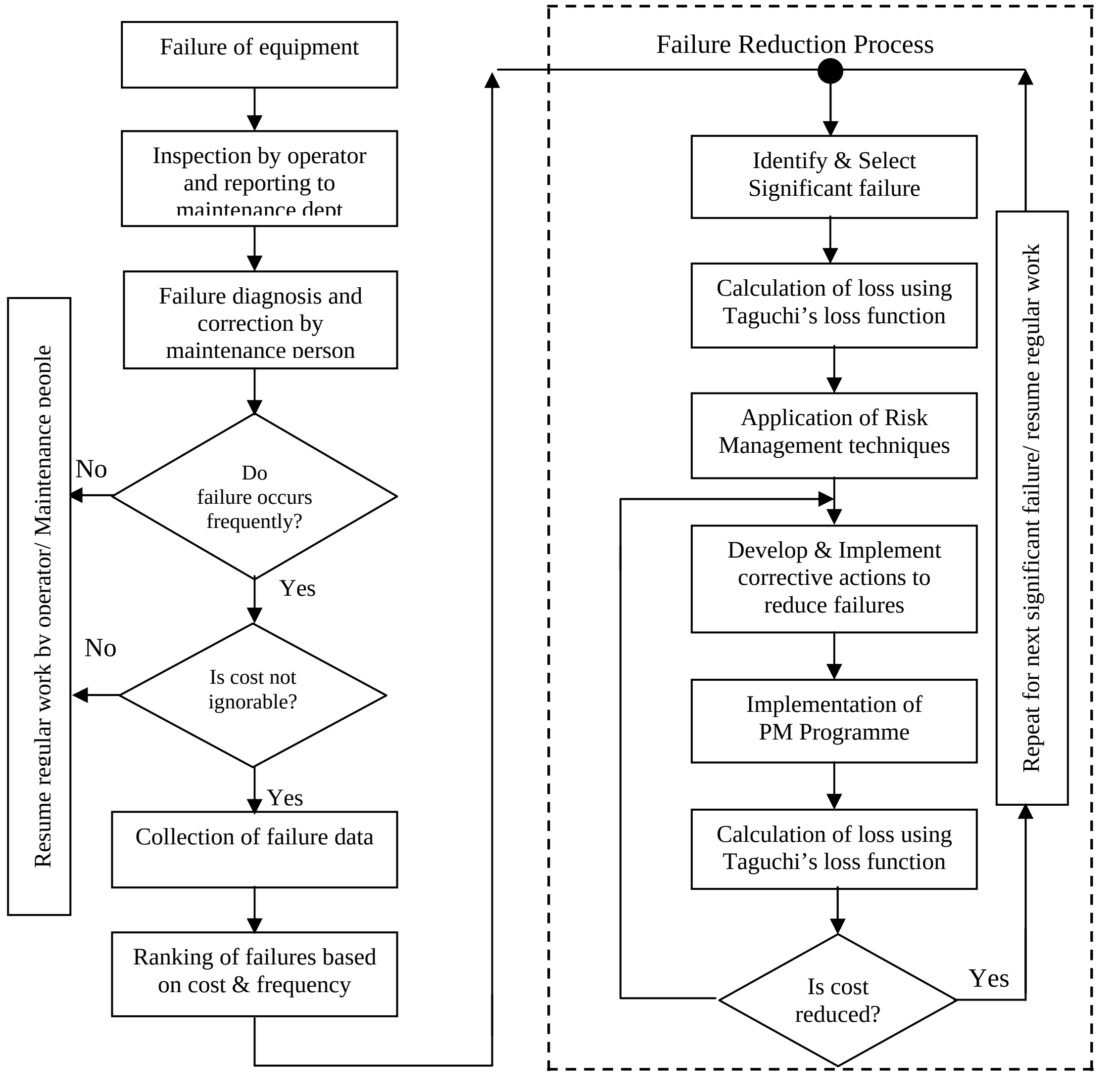
Risk assessment concepts are used to assess the significance of machine failures and the most significant failure is initially selected for analysis to achieve maximum benefits (Coppendale, 1995; Schlechter, 1996). In this concept, significance of each failure is assessed by assigning weightings to both cost consequence and frequency of occurrence. Cost consequences are categorized into various levels to indicate the severity based on the cost: Catastrophe, Very critical, Critical, Medium, Minimal and Very low assigning with suitable weightings. The consequence range is variable one according to the organizational structure and financial scale of operations and assessed based on the lowest and highest cost of the failures under consideration. Similarly, frequency of occurrence of each failure is also categorized into various levels: Regular, Probable, Can happen, Low likelihood, Rare and highly unlikely assigning with suitable weightings. A weighting matrix is formed by dispersing the failure consequence weighting in row wise and failure frequency weighting in column wise. Failures are located in weighting matrix cells based on the weightings of cost consequence and frequency. Now failures can be ranked based on the product of weightings of consequence and frequency. Top ranked failure which is considered to be a significant failure is initially taken for analysis to have maximum cost benefits.

DEVELOPMENT OF RMM

In general, maintenance personnel replace the failed machine part in the event of failure to normalize the machine for regular work. In most of the cases, maintenance personnel get into their routine work and the causes of part failure are not investigated to avoid them in future. The existence of loss producing manufacturing environment necessitates the development of a RMM to analyze and reduce the machine failures. The Figure 1 illustrates the steps involved in RMM to analyze the machine failures.

In the event of machine failure, the operator reports the details of the failure to the superior and then to maintenance department immediately. The maintenance personnel rectifies the machine and record details such as maintenance starting time, maintenance finishing time, down time, spare part description and cost of spare part.

Figure 1 Reactive Maintenance Model



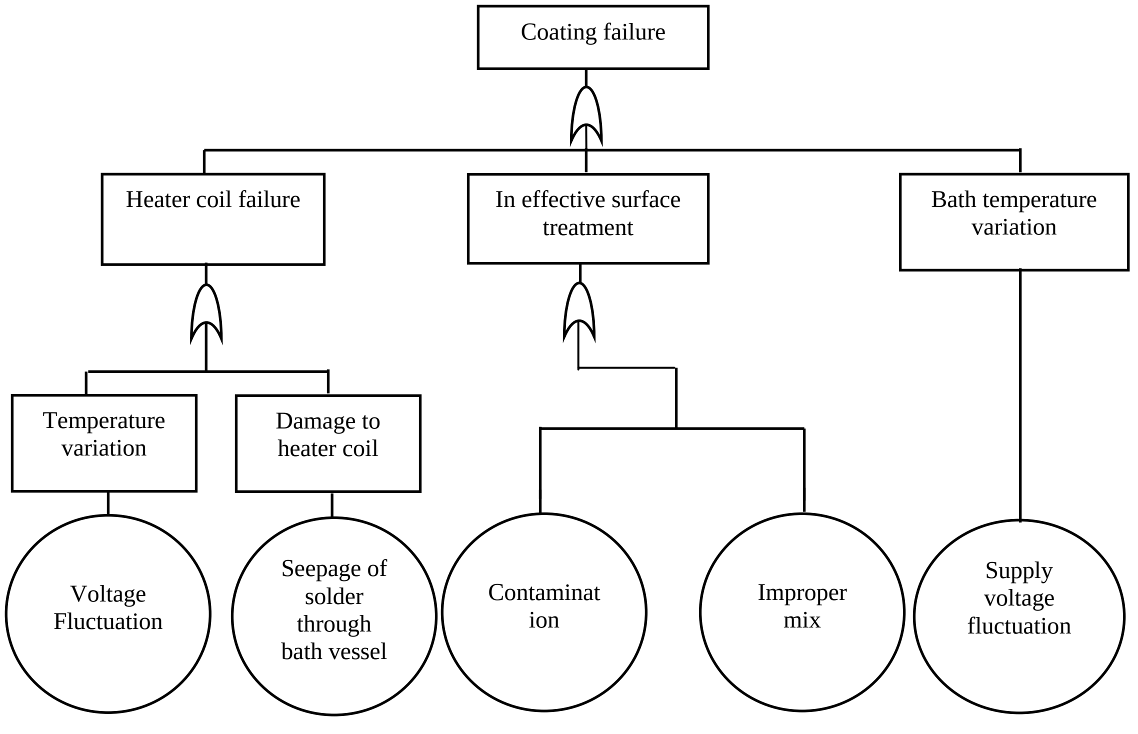
The maintenance person (or analyst) evaluates the significance of that failure in terms of cost incurred and frequency of occurrence. If the adverse effect of the failure is not ignorable, the analyst collects the details of the failures occurred in the past from the records for sufficient span of time. The various failures occurred during the considered period are listed for which the total cost incurred and frequency of occurrence are evaluated. Cost consequence and frequency of occurrence of failures are categorized into various levels to quantify the risk involved in them (section 3). The top ranked failure is considered to be the significant failure among the listed failures. If the cost of the significant failure is intolerable, one of the RMTs is applied to analyze the causes of that failure in order to have considerable financial gain by the way of designing and implementing the corrective measures. The cost incurred for that failure is appraised for the monitored period to evaluate the effectiveness of the corrective actions implemented. If the cost of that failure is reduced to acceptable level the same failure reduction process of the model is applied to the next significant failure. The analyst resumes regular work if the adverse effects of failures are within the acceptable level.

FAILURE ANALYSIS AND LOSS ASSESSMENT

In this study, the failures of solder coating machine - a special purpose machine used in radiator manufacturing is taken for analysis. Brass coil having cross section of 31 mm x 0.1 mm is coated with solder material, which is later drawn into radiator tubes. Brass coil available in the form of reel is passed through water based chemical solution for surface treatment to remove oil, dirt and other surface impurities. Solder material made out of lead and tin is melted in a stainless steel bath using heater coils. The treated brass coil is passed through solder bath maintained at 330°± 15° C to provide uniform coating of 0.1±0.05 mm. The processed coil is cooled immediately by passing through water bath and finally wound on a spool.

Among the failures, coating failure is taken for analysis as it affects the succeeding tube drawing process severely. Coating failure is said to be occurred when the coating thickness is out of the dimensional specification. In our case, the failures that give rise to coating failures are categorized into operator failures, material failures and random failures. The causes of failures in all categories are analyzed using the Fault Tree Diagram, one of the risk management tools as shown in Figure 2.

Figure 2 Fault Tree Diagram for coating failure



The Fault tree diagram is constructed with 'coating failure' as top event and other dependent and independent causes are related in the diagram. The costs of the various failures indicated in the FTA are collected from 01.06.04 to 31.12.04 and given in Table 1.

Heater failure, coating failure due to voltage fluctuations and bath vessel failure are classified as random failures because of its random nature; coating failure due to improper surface treatment is classified as operator failures because it is independent of machine condition, occur due to negligence of operators. The cost of each failure is calculated by accounting the spare cost, manpower cost, down time cost and overhead cost. During the data collection period, the machine was operated for single shift per day and 25 days in a month.

Table 1 Details of failures in Solder coating machine (before model implementation)

Description of failure	Down Time in hrs – [Frequency]	Cost in Indian Rupees				
		Downtime loss	Spare parts	Matl. Damage	Man power	Total
Heater failure	13.6 [08]	1,360	6,000	-	850	8,210
Coating failure by voltage fluctuation	20.7 [18]	2,070	-	-	620	2,690
Coating failure By poor surface treatment	23.2 [15]	2,320	-	-	670	2,990
Material failure	7.0 [05]	700	-	3,000	210	3,910
Bath vessel damage	6.0 [02]	600	1,600	6,00	360	3,160

Coating thickness is considered to be a functional parameter and checked in regular intervals as it affects the quality of the radiator. A vernier caliper having one micrometer least count is used to measure the coating thickness and is calibrated at regular interval to ensure its quality of measurement. PM and other adjustments are made in the machine whenever required to maintain the coating thickness (functional parameter). The money spent for unit running time of machine to maintain the coating thickness is estimated by applying Taguchi's loss function as given in the equation 2.

It is observed that whenever the coating thickness deviates beyond ±0.05 mm affects the subsequent tube drawing process and yields significant loss. If the coating thickness exceeds the limits (coating failure), the coil will be recoated to correct the coating thickness. To avoid the losses, whenever the coating thickness reaches the limit of ±0.03 mm necessary preventive measures and adjustments are made to bring the coating thickness with in the limits. The various parameters and cost involved in maintaining the coating thickness is expressed in the Taguchi's loss function. This function expresses how much money is currently spent per unit running time to maintain the coating thickness. The various parameters required to estimate the loss as per the loss function are given as follows. The measuring instrument calibrated at a cost of Rs. 600 at an interval of 1200 hours is accounted as checking cost. PM is scheduled once in 600 hours to up keep the coating machine at a cost of Rs 500. The cited data categorized are consolidated as given below to apply in Taguchi's loss function equation. Checking cost (B): Rs 725 (including depreciation of measuring instrument of cost Rs. 5000 having life of 10 years); Checking interval (n_o) : 1200 hours; PM cost(C) : Rs 500.00; Average PM Interval (u_o) : 600 hours; PM limit (Δ) : ± 0.03 mm on coating thickness; Functional limit (Δ^*): ±0.05 mm of coating thickness; Loss per random failure (C^*) : Rs 502.00; Mean time between random failures (u^*) is 43 hours; Time lag (ζ) : 0 ; Material failures cost (C_m) : Rs 782; Mean time between material failures (u_m) :240 hours ; Operator failures cost (C_l) : Rs 200 ; Mean time between operator failures (u_l) : 80 hours . Loss per hour running of machine due to failures as per the Taguchi's equation is given below.

$$L = \frac{725}{1200} + \frac{500}{600} + \frac{502}{43} \times \frac{1}{0.05^2}\left(\frac{0.03^2}{3} + \left\{\frac{1200}{2} + 0\right\}\frac{0.03^2}{600}\right) + \frac{782}{240} + \frac{200}{80}$$

Rs. 12.79 is spent in each hour of machine running for maintenance, failure correction and checking the functional parameter in order to maintain the coating thickness. The loss calculation reveals that the random category of failures is the most significant failures that contribute for coating failures. The combination of material failures and operator failures affect the coating thickness equally as that of random failures. Hence, the loss due to material failures and operator failures are also not ignorable. Various failures encountered in the coating process are discussed in the following section.

Solder material is melted in a bath using heater coils. Wide fluctuations in supply voltage affect uniform heating of solder material that causes non uniformity in temperature distribution in the solder bath. Evenness of coating thickness on the brass coil is affected due to the temperature variations and gives rise to problems in the subsequent tube drawing process. Wide fluctuations of supply voltage also cause thermal fatigue in heater coils and leads to premature failure of heater coil. Supply voltage when reaches the higher level beyond working range weakens the heater coil and causes its failure. The discussed failures are controlled by maintaining the solder bath temperature by incorporating a voltage regulator and relay circuit at a cost of Rs. 12,000 to the power supply of the solder coating machine. If bath temperature varies, supply voltage level is adjusted using the voltage regulator to maintain the solder bath temperature. Incorporation of the voltage regulator eliminates voltage fluctuations which in turn enhances the working of the heater coils. When the temperature range deviates beyond the set limit, the relay circuit is tripped to ON and OFF accordingly so that the heater coil failure due to high voltage range is eliminated. The presently used locally available heater coil is replaced with good quality heater with an increased cost of Rs. 400. Coating thickness is inspected for every hour to ensure the required specification. In case of any variation in coating thickness, temperature is adjusted and the coating thickness is brought to the required value.

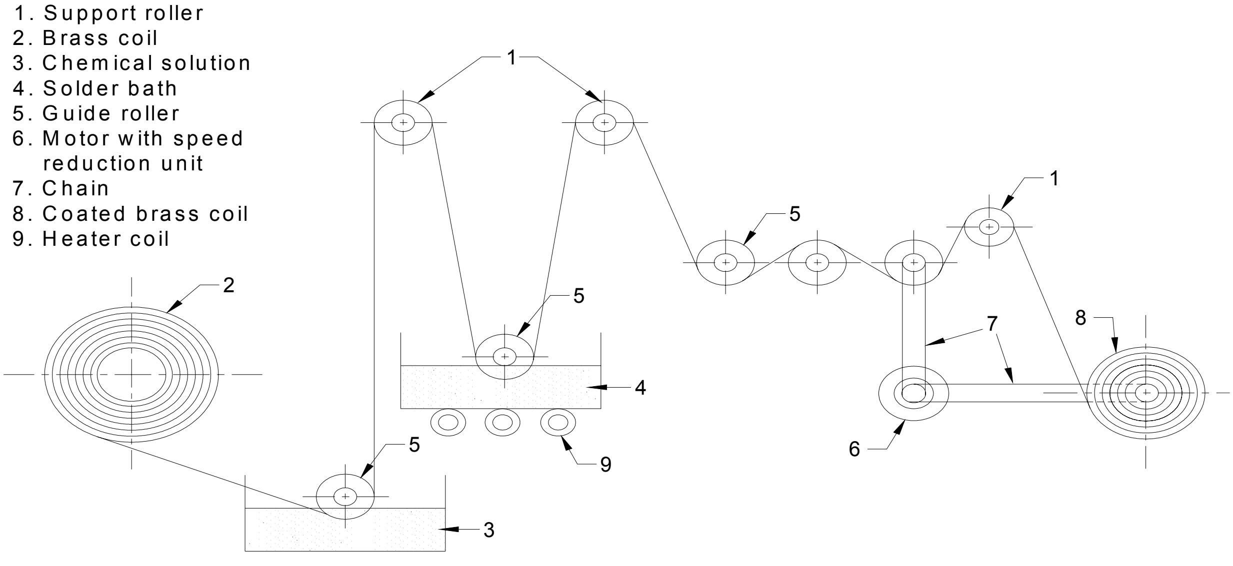
In the coating machine, brass coil is passed through water based chemical solution for surface treatment. The solution is prepared by mixing ammonium chloride, zinc chloride, and hydrochloric acid with water. The chemical solution if not maintained properly at regular intervals, looses its required property due to dilution and contamination. The contamination of chemical solution in prolonged use could not provide effective surface treatment and leads to coating failure. In such conditions, solder material deposits as small lumps on brass coil in random manner which is not suitable for further processing in the next machine. The discussed coating failure due to poor surface treatment is minimized by checking the degree of contamination of chemical solution, measuring its pH level at regular interval. Necessary additives are added whenever required to maintain the quality of the chemical solution.

Rejection of defective coil after processing incurs significant loss in the form of loss of effective production time, labor, and wastage of solder material. The defective coils if screened before processing can be returned to the supplier for replacement. But, if rejected after processing it cannot be returned to the supplier for replacement and become scrap. The discussed failure is avoided by conducting in coming inspection to screen the coils for defects like hard spots, surface damages, holes and dimensional variations. Inspection is done at cost of Rs. 200 per month on brass coils to check the dimensional specifications and physical damages. The identified defective brass coils are eliminated from processing.

Solder bath vessel made out of 2.03 mm (14 SWG) thick stainless steel sheet is subjected to high temperature and chemical reaction with solution present in the surface of the coil, damages the bath vessel in the form of erosion and pin holes. The brass coil treated in chemical solution is passed to the solder bath immediately for coating. The chemical solution adhered to the surfaces of the brass coil reaches the solder bath and damages it by reaction. Bath vessel damage due to chemical reaction is not identifiable when occurs as the bath contains liquid solder or residual solidified solder always. At the time of bath damage, falling of liquid solder material on the heater coil due to seepage through pin holes causes the heater failure. The discussed failures are reduced by controlling the quantity of flow of chemical solution to the solder bath in order to minimize the chemical reaction. The brass coil after having surface treatment in the chemical solution is immediately passed through the solder bath for coating. The coil is supported by a roller in between the chemical solution bath and solder bath. The guide roller is elevated to higher level to drain down the excess chemical solution which moves along with the coil surfaces in order to minimize the quantity of chemical solution that reaches and reacts with bath vessel at a cost of Rs. 400 as shown in the figure 3. The thickness of the bath vessel is increased from 2.03 mm (14 SWG) to 3.25 mm (10 SWG) to have extended life. Due to the increase in the thickness, the cost of the bath vessel is also increased from

Rs. 800 to Rs. 1400. Heater coil failures due to falling of solder material are reduced considerably as the supplementary benefits for the corrective actions taken to reduce the bath failures.

Figure 3 Schematic arrangement of the coating machine



In addition to the above corrective measures, the management has conducted training programmes to the workers in order to bring awareness on the engineering aspects around which they are working. The inexperienced workers who were tuned to the requirements are provided with a one week, two hours per day, awareness cum training programme to instruct on the functioning of the various elements of the coating machine at a cost of Rs. 600. The various activities involved in coating process such as incoming inspection, measurement of coating thickness, preparation and inspection of quality of chemical solution are explained and demonstrated for the operators. The maintenance personnel also trained on 'RMP and RMT' for two weeks, two hours per day at a cost of Rs.1000 to apply the RMM practically.

DEVELOPMENT AND IMPLEMENTATION OF PM PROGRAMME

It is observed that whenever the coating thickness deviates beyond ±0.05 mm affects the subsequent tube drawing process and yields significant loss. If the coating thickness exceeds the limits, the coil will be recoated to correct the coating thickness. To avoid the losses, whenever the coating thickness reaches the limit of ±0.03 mm necessary preventive measures and adjustments are made to bring the coating thickness with in the limits. The activities to be carried out for controlling the deviation are brought out as a part of PM programme. When the coating thickness on the brass coil reaches the maximum limit because of low temperature, one has to do the preventive measures as given in Table 2.

Table 2 PM activities for the maximum limit of coating thickness

Event	Reason	Corrective Action
Low Temperature of solder bath	Deterioration of heater coil, unable to generate required heat.	Replace the heater coil with new one.
	Heater coil failure due to seepage of solder material through the pin holes of the damaged bath vessel	Rectify the vessel damage or replace the bath vessel with new one.
	Low Supply voltage	Adjust the regulator to maintain the supply voltage to the possible extent
Deposition of solder material as small lumps on the brass coil	Improper condition of the chemical solution	Check the ph level of the chemical solution and maintain the ph level by adding suitable additives.

When the coating thickness on the brass coil reaches the minimum limit because of high temperature, one has to do the preventive measures as given in the Table 3.

Table 3 PM activities for the minimum limit of coating thickness

Event	Reason	Corrective Action
High Temperature of solder bath	Molten solder bath quantity reduction in bath vessel	Ensure the quantity of the solder material in the bath vessel by adding the required quantity of pre-cast solder ingots.
	High supply voltage	Adjust the voltage level

RESULTS

In this study, coating thickness variation on the brass coil is analyzed with a view to reduce failure cost and to minimize materials wastage. Corrective measures are taken to eliminate the causes of uneven coating thickness. The effect of implementation of RMM is observed for three month from February 2005 to April 2005. It is observed that after practicing RMM, the coating failures and other associated failures are reduced considerably. The maintenance cost is increased from Rs. 500 to Rs. 1000 for the observed period, accounts for additives added for maintaining the quality of the chemical solution and replacing the unconditioned small parts of the machine. Rs. 200 per month spent for incoming inspection is accounted for failure cost by processing defective material (C_m) as it is used to screen the defective coils. The costs details of failures after implementing the RMM are given in Table 4.

Table 4 Details of costs of failures in Solder coating machine

Description of failure	Down Time in hrs – [Frequency]	Cost in Indian Rupees				
		Downtime loss	Spare parts	Matl. Damage	Man power	Total
Heater failure	-	-	-	-	-	-
Coating failure by voltage fluctuation	2.2 [04]	220	-	-	70	290
Coating failure By poor surface treatment	1.8 [03]	180	-	-	60	240
Material failure	1.2 [02]	120		180	40	340
Bath vessel damage	-	-	-	-	-	-

The various cost parameters used in the equation 2 are calculated from the details available from the Table and is given as follows. PM cost (C) is Rs. 1000; PM interval 600 hours; Average loss per random failure (C^*) is Rs. 600; Mean time between random failures (u^*) is 600 hours; Time lag (ζ) is 0 hour; Material failure cost (C_m) is Rs 470; Mean time between material failures (u_m): 300 hours; Operator failure cost (C_l): Rs 120; Mean time between operator failures (u_l): 85.7 hours. Coating failure due to voltage fluctuation is now accounted for operator as it can be controlled by manually after installing the voltage regulator. There is no random failure has occurred during the study period of three months.

Heater coil is expected to have life of six months after which it has to be replaced with new one at a cost of Rs. 1200. Half of the heater cost is accounted in random failure cost while estimating the loss during the observed period of three months. The half of the operator training cost is accounted under for operator failure category in the equation.

$$L = \frac{725}{1200} + \frac{1000}{600} + \frac{600}{600} \times \frac{1}{} \frac{0.03^2}{0.05^2}\left(\frac{1200}{3} + \left\{\frac{0.03^2}{2} + 0\right\}\frac{}{600}\right) + \frac{470}{300} + \frac{120}{85.7}$$

$$= 0.60 + 1.67 + 0.48 + 1.6 + 1.4 = \text{Rs. } 5.75 \text{ / hour}$$

Loss before implementing RMM is Rs. 12.79 per hour and Loss after implementation is Rs. 5.75 per hour. Money saved (%) due to RMM is (12.79 -5.75) / 12.79) x 100 = 55 %. After practicing the cited maintenance schedule and procedure, loss due to uneven coating thickness and related failures is reduced by 55 %. The out come of the implementations was appreciated by the user and shows interest to apply the model for other machines also. The money spent per unit time to maintain the solder coating thickness (functional parameter) is appreciably reduced on overall basis. The functional parameter checking cost is unaffected since the checking interval is not changed. Increase in maintenance cost is witnessed during the observation period due to the maintenance activities taken whenever the functional parameter deviates from the limits. It is accepted as long as there is a large financial leverage on failure cost to the maintenance cost. The material and operators failures are also considerably reduced by practicing incoming material inspection and providing employee training. However, the present trend is not taken on concrete basis as the observation period is very short and needs further observation. The failures in the successive tube drawing process are also considerably reduced.

DISCUSSION

Machines and processes have parameters that significantly affect the quality of the output of the machine or process concerned. The parameter known as functional parameter is identified for which efforts are taken to maintain them within the limits in order to get quality output. Taguchi's loss function is used to estimate how much money is spent per unit time to maintain the parameters whereas the risk management technique is used to reduce the losses. The losses which are termed as failures are analyzed one at a time. Once, the failure taken for analysis is reduced to acceptable level the next significant failure will be taken for mitigation. This methodology is very much effective to assess the existing failures in the machine or process at any instance. It also shows the varying nature of significance of failures and rising of new failures in the machine or process. The frame work of the methodology allows the marginal increase in maintenance cost in order to have significant financial gain by the way of reduced failures. The successful implementation and continued practice of the model requires supporting activities like introduction of inspection procedures and means for employee performance improvement. The additional expenditure in these heads is accounted appropriately in the loss function to estimate the cost. The model is considered to be successful one if the organization realizes benefits in terms of reduced failure costs, operators improved performance.

CONCLUSION

The study was conducted with an objective of reducing the machine failures as described in the Taguchi's loss function for PM section. An attempt is made to reduce the acknowledged machine failures using risk management approaches with loss estimation technique. The systematic framework of the model performs technical risk assessment to identify the prime causes of machine failures, considering their frequency as well as severity, finds the ways to reduce them on analysis. Condition based maintenance is performed whenever necessary to keep the parameter with in the limits which is otherwise leads to failure. Though there is an increase in maintenance cost, considerable reduction in failure cost is witnessed. The loss incurred per hour of machine running to ensure the quality output is reduced from Rs. 12.79 to Rs. 5.75 for the observation period of three month. Though it is earlier to conclude that the cost trend is consistent one, the initial period of model implementation shows considerable savings in the failure costs. If the same cost trend is exists there will be a savings up to Rs. 16,000 for one year. It is understood that the same method is adopted for other processes, it is possible to reduce the failures in that processes significantly.

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