Failure Mode Effect Analysis: Process Capability Enhancement-A Case Study

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ABSTRACT
A process capability is a numerical summary that compares the behaviour of a product or process characteristics to engineering specification. Process capability in a manufacturing process is an operational failure which might result in undesired quality of product or increases the scrap rate of an organisation. A number of precautions should be taken in to account in order to prevent/reduce the occurrence probability of reduction in process capability of a grinding machine.(as case study taken for CNC grinding machine)This paper make use of Failure Mode Effect Analysis(FMEA) to adopt the innovative technologies integrated with the operational aspects in order to enhance the process capability. The main objective of the study is to improve machinery system reliability and to enhance operational safety concept of CNC grinding machine.

Key words: Process capability (cpk), Failure Mode Effect Analysis (FMEA) Track Grinding, Risk Priority Number(RPN),

1. Introduction:

In order to evaluate & optimise the grinding machine performance, we must focus on the entire grinding process. A grinding machine is much more difficult to control than other machining process.

The case study was carried out in the bearing manufacturing company. The product taken under consideration was Outer Ring of TRB (Taper Roller Bearing) which consists of four parts as Outer ring, inner ring, outer cage, & Tapered ball. The problem statement was for channel No.3 at TRB section at company as total scrap was 6200 ppm. The Pareto analyses were done to select the CNC grinding machine as it contributing 42% of the total scrap quantity. This also results in shortage of outer ring in the assembly section thus, reducing the net output of the channel. Hence the initial data were collected on the track grinding machine and capability index (cpk) was calculated as 1.19. The obtained cpk was not as per requirement to get the process stable.

Hence from the process map study various process inputs were collected which has their effect on the output i.e. track grinding of outer ring. After that cause-effect matrix study were done. From the cause-effect matrix according to the importance to the customer some input steps required for operation were selected. Since the critically important steps for the capability enhancement for grinding machine precautions are extremely vital. Therefore this paper utilized the Failure Mode Effect Analysis (FMEA) approach to formulate satisfactory solutions to prevent capability index (cpk) to come down. The potential risk associated to the grinding machine performance clarified based on FMEA. Hence the significance of the proposed idea lay to the transforming of operational feedback and evidences to prevention action against machine performance.

The organisation of this paper given as this section begins with motivating information on the paper. In section 2, a brief introduction to FMEA is given. In section 3, the application of the FMEA on to the process capability index enhancement for CNC grinding machine. In section 4 the conclusion remarks are expressed.

2. Failure Mode Effect Analysis (FMEA)

FMEA is a proactive analysis tool allowing engineers to define, identify and eliminate known /or potential failure, problems, errors and so on from the system, design, process /or service,[omdahl, 1988,stamatis2003]

FMEA is an inductive approach to support risk management studies and the principles of FMEA is to identify potential hazards along with the focused system and to prioritize the required corrective actions or strategies. In 1949 the FMEA methodology was developed and implemented for the first time by the United States army and then in the 1970 with its strength and robust characteristics its application extended to aerospace and automobile industry, to the general manufacturing.[9]

Now a day's FMEA mainly applied in industrial production of machinery, motors cars, mechanical and electronic component. FMEA is a procedure in product development and operation management for analysis of potential failure modes within a system for classification by the severity and likelihood of failures. A successful FMEA activity helps a team to identify potential failure modes based on the past experience with similar product or process or problem, enabling the team to design those failures out of the system with the minimum of efforts and resource expenditure thereby reducing development time and cost. It is widely used in manufacturing industries in various phases of product life cycle. Applying FMEA involves number of steps starting from analysis of product, process or system in every single part, list of process steps, process inputs, then list of identified potential failures, evaluation of their frequency of occuranace,severity(Its effect on process/product/system and to its surroundings in case of failure) and their detection

FMEA should be initiated by the design engineering for the hardware approach and the system engineering for the functional approach. Once the initial FMEA has been completed, the entire engineering team should participate in review process. FMEA cannot be accomplished on an individual basis because FMEA is team function. The FMEA team reviews for identifying high risk areas that must be addressed to ensure completeness. A various expertise people from different areas can participate in FMEA activity, for instance project manager, design engineer, test engineering, maintenance and safety engineering, operator etc. The expertise team can vary according to the scope and complexity of the focused failure problems. The group leader/co-ordinator, preferably FMEA experts organizes the expert team activities in accordance with FMEA theory and data can be collected during work.

The most important aspect of FMEA is the evaluation of the risk level of potential failure identified for every sub-process. The value of damage caused on system by every failure indicated with the Risk Priority Number (RPN). A FMEA uses the RPN to assess the risk in three categories: Occurrence (O) is the assessment for how frequently the problem occurs within system, Severity(S) is an assessment of seriousness of the effect of potential failure to the process or system or surrounding and Detection (D) is the assessment of the probability of detection of occurred problem with available monitoring system before component/system is damaged and stopped.

The RPN is generated by taking the product of three index (occurrence, severity, detection) on the scale from 1-10 for each one . Hence RPN number will decide the seriousness of potential risks critical to safety of system or productivity of process.

RPN=S*O*D

FMEA document shows a list of items that identified:- (i)Process steps (ii) Process inputs (iii) potential failure mode(iv) potential effect of failure(v)potential causes/mechanisms of failure(vi)Severity index (vii)Occurrence index (viii) Detection index (ix) Risk Priority Number. Table 1-3 shows quantitative scales commonly used for the occurrence, severity and delectability index.

TABLE: 1

RATING	EFFECT	SEVERITY OF EFFECT
10	Hazardous without warning	Failure could injure the customer or an employee.
9	Hazardous with warning	Failure would create noncompliance with federal regulations.
8	Very high	Failure renders the unit inoperable or unfit for use.
7	High	Failure causes a high degree of customer dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product
5	Low	Failure creates enough of a performance loss to cause the customer to complain.
4	Very Low	Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss.
3	Minor	Failure would create a minor loss to the customer, but the customer can overcome it without performance loss.
2	Very Minor	Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product.
1	None	Failure would not be noticeable to the customer and would not affect the customer's process or product.

TABLE: 2

RATING	PROBABILITY OF OCCURANCE	POSSIBLE FAILURE RATE
10	Very High:	More than one occurrence per day
9	High:	One occurrence every three to four days
8	High:	One occurrence per week
7	High:	One occurrence every month
6	Moderately High:	One occurrence every three months
5	Moderate:	One occurrence every six months to one year
4	Moderately Low:	One occurrence per year
3	Low:	One occurrence every one to three years
2	Low:	One occurrence every three to five years
1	Remote:	One occurrence in greater than five years

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3. APPLICATION

3.1 Introduction to case study

The case study has been taken for the process capability enhancement of CNC grinding machine. The particular case study carried out at one of bearing manufacturing company. The scrape for TRB (Tapered Roller Bearing) on channel no.3 was 6200 ppm. The pareto analysis were done & OR (outer ring) track grinding machine selected for further improvement/ enhancement because it contribute 42% total scrap. Fig 1 shows parato analysis and fig.2 shows outer ring taken under consideration.

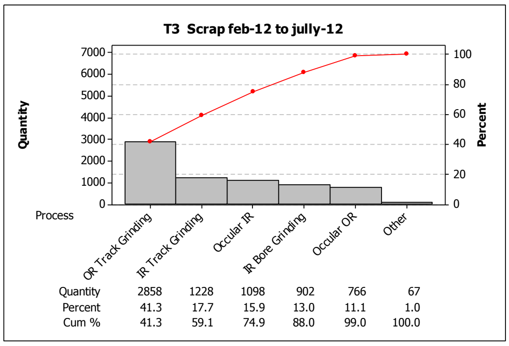

Fig:1 Pareto analysis

Fig:2Outer ring

Initial data were collected on the machine for inner diameter of outer ring & process capability (cpk) was calculated as 1.19 which is lower than the required to keep the process smoothly Shown in fig. No.3[7]

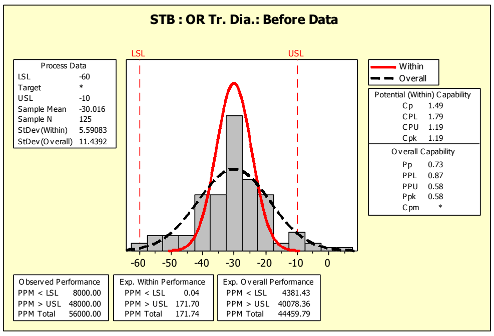

Fig:3 Initial capability analysis(cpk 1.19)

The process capability is an important concept for industrial people to understand how well a process can produce acceptable product. As a result, a manager or engineering can prioritize needed process improvements and identify those processes that do not need immediate process improvement. The process capability study indicates if a process is capable of producing virtually all conforming product. If the process is capable then statistical process control can be used to monitor the process and conventional acceptance efforts can be reduce or eliminated entirely. This not only yields great cost savings in eliminating non-value added inspection but also eliminate scrape, rework and increase the customer satisfaction.

CNC grinding machine grinds the track diameter (Inner diameter) of outer ring of TRB. From the process map analysis different input parameters required for the track grinding which affect the output.(i.e. Track dia of ring)is selected. The selected various inputs from process map carried further for the cause –effect matrix. In this analysis according to the rating of importance to the customer few critical inputs were selected.i.e.clamping pressure, ,work head rpm , roller screw condition for cross-slide movement, cutting speed ratio, grinding compensation, grinding compensation interval, dressing interval and dressing arm repeatability dressing play, work head pulley,dimond height, shoe condition, and spindle nose condition. These inputs are further selected for FMEA. Although great efforts have been made to maintain & improve the performance of grinding machine, it can not be entirely controlled. It can be minimised by implementing new maintenance regimes, integrating advance technologies in to system comply with company rules and regulation and other safeguards. The causality nature should be identified via using evidence & past experience. Recalling historical development background of capability enhancement of similar type of machine will help to a great extent. The operational survey conducted hereby guides this study in order to structure the methodological procedure based on FMEA.

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Table No.4: FMEA: Analysis Worksheet

PROCESS STEP	PROCESS INPUT	FAILURE MODE	FAILURE EFFECT	FAILURE CAUSE	S	O	D	RPN
Cross slide movement	Roller screw condition	Play in slide	Size variation	Basic wear &tear in screw	8	5	7	288
Grinding process	Cutting speed ratio	Speed ratio not achieved	Ovality problem	Spindle speed & w/h speed not set	8	5	6	240
Grinding process	Grinding compensation	Uneven grinding	Size variation	Values not set as per chart	8	3	9	216
Grinding process	Dressing compensation	Uneven grinding	Size variation	Values not set as per chart	8	3	9	216
Grinding process	Grinding compensation interval	Cycle time and wheel consumption	Cycle time & wheel consumption increases	Values not set as per chart	8	3	9	216
Dressing	Dressing arm up/down sensor	Uneven dressing	Chatter on surface	Life of sensor & its accuracy	7	3	10	210
Ring clamping/De clamping	Clamping pressure	Clamping pressure not ok	Size variation	Pressure regulators not working	8	4	6	192
Grinding process	Work head rpm	Low/high speed	Size variation	Incorrect setting	8	4	6	192
Dressing	Dressing play	Uneven dressing	Visual defect and ovality	Mounting for dressing not ok	7	5	5	175
Work head rpm	Work head pulley	Sleeping of belt	Size variation	Rpm not reached	7	3	8	168
Dressing	Diamond height	Diamond height +/-	Ovality	Initial set up not ok	7	4	6	168
Ring rotation	Shoe condition	Shoe worn out	Size variation& ocular bad	Improper setting	8	5	3	120
Grinding process	Clamping pressure	Low/high pressure	Size variation	Incorrect setting	8	5	3	120
Grinding process	Spindle nose condition	Spindle nose run out more than10 micron	Size variation	Lack of maintenance	7	3	5	105

3.2Through the methodological approach

Conducting an initial survey to gather feedback/evidences from different capability enhancement projects in the company itself. A required level of knowledge to apply FMEA was enabled. The main goal of methodological approach to capability enhancement is to identify all aspects of failure & to suggest precautions that combine operational duties & technological means. Complying with FMEA application principles, the investigation team which contributes a FMEA practioner and couple of 6-sigma expertise were guided the following six main step:[2]

- Step 1: Brainstorm potential failure mode

  In this first step potential failure mode based on functional requirement are determined through brainstorming. They are enlisted in to the FMEA worksheet which is illustrated in Table No 4.

- Step 2: list potential effects of each failure mode.

  This step begin with ascertain potential effects for each failure mode by gathering feedback from experts.i.e starting from operator to manager. A cause effect analysis is carrying out during for identification of potential effect of each failure mode.

- Step 3: Assign on occurance ranking for each failure mode

  A team identified the potential cause of failure associated with each failure mode. This information not only helps likelihood of failure occurring but also helps target their improvement efforts.

- Step 4: Assign severity ranking

  Failure can have various efforts and each effect can have their different levels of severity. Parato analysis can be done at this step.

- Step 5: Assign Detection ranking

  In this step all controls currently in place for each of potential cause of failure or effects of failure are listed and assign detection ranking.

- Step 6: Calculate Risk Priority Number

  RPN number calculated for each failure mode by multiplying severity, occurrence, and detection numbers. According to results given in the table No.4 a highest score is 288 and lowest is 105 points.

3.3 Analysis and discussion:

To clarify the required precautions, the quantitative results derived from FMEA application to process capability enhancement should be emphasis in this section. First of all average of all computed RPN number is found as “188” that is recognised as the threshold value to decide whether the precautions are required or not. According to this assumption, a level of preventive actions or special attentions necessitates specially for process inputs such as roller screw condition, cutting speed ratio, grinding compensation, grinding compensation interval, dressing interval, dressing arm up/down sensor, clamping pressure and work head rpm as their High RPN value (i.e.288,240,216,216,216,210 &192). To express the utilization of FMEA application results on process capability of grinding machine results explain below.

1. Cross slide movement is most important process step to have proper grinding operation. For have proper closs-slide movement its roller screw condition should be maintained during each PM (Preventive Maintenance). During PM we found roller screw of cross-slide was damaged and so replaced.
2. Cutting speed ratio is the ratio of work head rpm to the spindle rpm. This rpm synchronised with the display unit to have proper and constant attention of operator.
3. Next is grinding compensation (movement of cross-slide towards the work head), grinding compensation interval (after how much ring the compensation should be given) and dressing interval (after how much rings the truing of wheel is necessary). For this data collected by setting different dressing interval to know the exact wear of grinding wheel which is most sever cause of diameter variation.

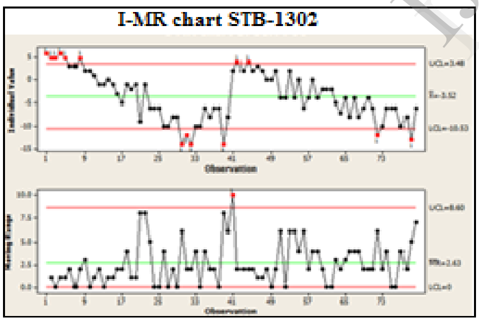

Figure 4:I-MR chart before

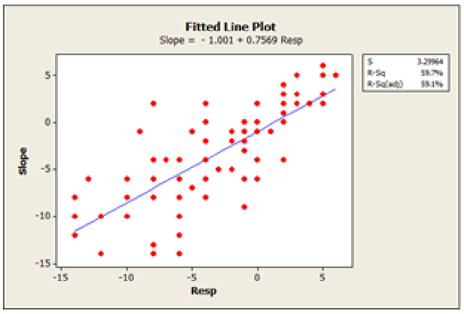

Figure5:Fitted line plot

I-MR chart shows gradually decreasing trend as dressing interval increases from 4 to 40 and fitness line plot shows that slope of the line is 0.7569. It indicates that there is a wear of 0.7569µm of grinding wheel per ring. Range chart is almost is in control up to initial 15 rings and 1 micron difference at interval of 3 rings. After studying the statistical behaviour of data collected it is found dressing interval of 15,grinding compensation of 1 µm and grinding compensation interval of 3.Then again reading were taken following graph shows that all reading are within control.(Fig.6)

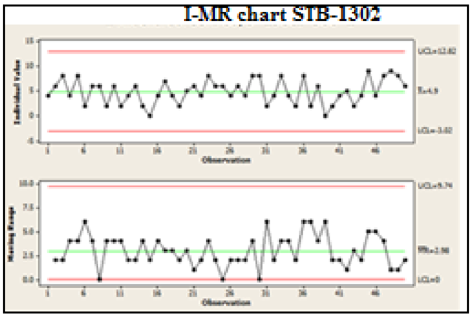

Figure 6: I-MR chart After

Note: Due to increase in dressing interval grinding wheel consumption is reduced and production rate also increased.

4. Dressing arm up/down sensor was not working properly so during preventive maintenance sensor checked. It was found not as per standard requirement so sensor changed.
5. Clamping pressure and work head rpm: To test the effect of work head rpm and clamping pressure on the track diameter of the ring the hypothesis testing was carried out & results are shown below.

I. Work head rpm:

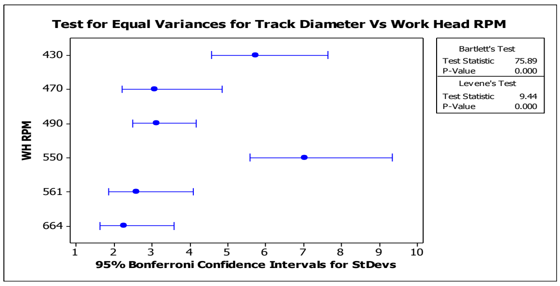

Figure7:Test for equal variance

95% Bonferroni confidence intervals for standard deviations

WH RPM	N	Lower	StDev	Upper
430	55	4.57432	5.75169	7.64831
470	25	2.21442	3.07300	4.84535
490	55	2.48639	3.12635	4.15726
550	55	5.58940	7.02805	9.34554
561	25	1.87068	2.59599	4.09322
664	25	1.63795	2.27303	3.58400

Bartlett's Test (Normal Distribution)
Test statistic = 75.89, p-value = 0.000
Levene's Test (Any Continuous Distribution)
Test statistic = 9.44, p-value = 0.000
P value =0, since the P-value <0.05,so the data shows that there is relation of work head RPM on track diameter.
Analysis shows that variable work head rpm impacts track diameter.

II. Clamping pressure:

Kruskal-Wallis Test: Track Diameter versus Clamping Pressure

Kruskal-Wallis Test on Track Diameter

Clamping Pressure

Att	N	Median	Ave Rank	Z
High	45	-23.50	63.5	6.52
Low	45	-29.00	27.5	-6.52
Overall	90		45.5	

H = 42.51 DF = 1 P = 0.000
H = 42.64 DF = 1 P = 0.000

P value = 0, since the p-value < 0.05, so the data shows that there is relation of clamping pressure on track diameter

Analysis shows that for clamping pressure impacts on the track diameter.

After corrective action taken on each failure mode their respective RPN number drop down considerably. Consequently FMEA for capability enhancement aid us to produce precautions both in operational and system design levels to prevent the risk.
After all corrective action completed data was collected for the track diameter and new improved capability index(cpk) got i.e.1.37.As shown in the fig.8

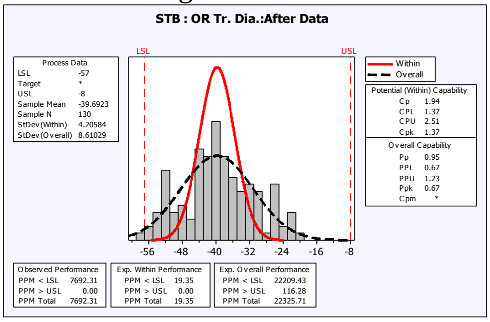

Fig:8 After capability analysis(cpk 1.37)

4. Conclusion:

Failure Mode Effect Analysis (FMEA) for capability enhancement requires great level of knowhow and competency. In addition methodological approach for this kind of technical problems should be considered to find satisfactory solution for different failure cases. This paper applied FMEA approach to capability enhancement. FMEA tend to give the importance to the prevention efforts, at point combined technical solution and operational precautions are proposed to prevent or decrease the probability of affecting machine performance.

Besides specific attempts to analysis capability improvement, the main task behind this paper is to express integrity of operational precautions and process technology in order to produce optimal solutions for process capability enhancement for grinding machine. Therefore improving the process system reliability and enhancing operational safety concept and for grinding machine. In addition to this, in this paper it is seen that FMEA is an adequate risk management tool in order to prevent the problems. As in the study cross slide movement, grinding compensation, grinding compensation interval, dressing interval, dressing arm repeatability, cutting speed ratio, clamping pressure and work head rpm are the crucial inputs to improve the process capability index.

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