TECHNICAL ARTICLE—PEER-REVIEWED

Failure Analysis and Improvement of Defective Clamping Pad During Leak Testing Process Using Kepner-Tregoe Analysis

Ravinder Jhorar · Vimal Kumar Pathak · Pooja Singh

Abstract In industries, the breakage of the clamping pad in the leak testing machine is a common and challenging problem during product quality control process. In the same context, it becomes essential to identify the possible causes creating hindrance to component clamped on leak testing machine. This paper presents a systematic and iterative methodology for analysing the failure and providing possible improvements in clamping pad for the successful operation of leak testing machine. The investigation of working environment of leak testing machine, Kepner-Tregoe (K-T) analysis, seven quality control tools, and quality circle concept are used to provide the root cause of the cracks and failure of clamping pad. Based on the failure analysis, suitable actions are suggested and implemented with process redesign. The improved process design led to negligible failures from the preliminary failure rate. The entire methodology is universal in nature and can be employed for failure analysis in a wide variety of industrial problems.

Keywords Leak testing · K-T analysis · Clamping pad · Failure analysis

Introduction

With the increasing demand of high-quality and high-performance components, the process of testing and inspection becomes inevitable in quality control of manufactured parts [1]. Crack or leak occurrence, surface blemishes, and

R. Jhorar · V. K. Pathak (✉) · P. Singh
Department of Mechanical Engineering, Manipal University Jaipur, Jaipur, Rajasthan, India
e-mail: vimalpthk@gmail.com

substantial failures are of significant interest in most of the manufacturing scenarios [2]. To this end, leakage testing is considered as one of the important processes in production lines to detect cracks or leaks within an engineering component. Additionally, the process of leak testing triggers most of the bottlenecks during the quality control of any manufactured components [3]. In complex shaped engineering components, like cylinder head, it is rarely possible to measure or detect the irregular and small dimensions of leak. A leak can be referred as flow of gas or liquid from the component due to imperfection such as a hole, crack, or bad seal. Typically, the leakage testing method aims at initially clamping the component on a fixture, pressurizing it with air, and finally submerging the component in water. The presence of leakage and internal cracks if available is visually visible in the form of bubbles [4]. The method of leakage testing is mandatory in a way to localize the leak, hole, or porosity while maintaining the integrity of a manufactured component and thus protects it from failure during its actual operation. In addition, for automobile applications, leakage testing of cylindrical block is essential to prevent poor engine performance as it is the first indication of crack in cylindrical block that can adversely affect the efficiency of vehicles.

In industries, the failure of leak testing process can cause possible failure of industrial component and finally scrapping of the components that may have performed adequately in field. Thus, failure analysis becomes indispensable and can be considered as an effective tool to reveal the causes of failure [5]. Nowadays, the process of leak testing is commonly performed using specific leak testing machine. The component is cautiously clamped on a leak testing machine and tightened using clamping holder on the fixture plate. The leak testing machine is a special
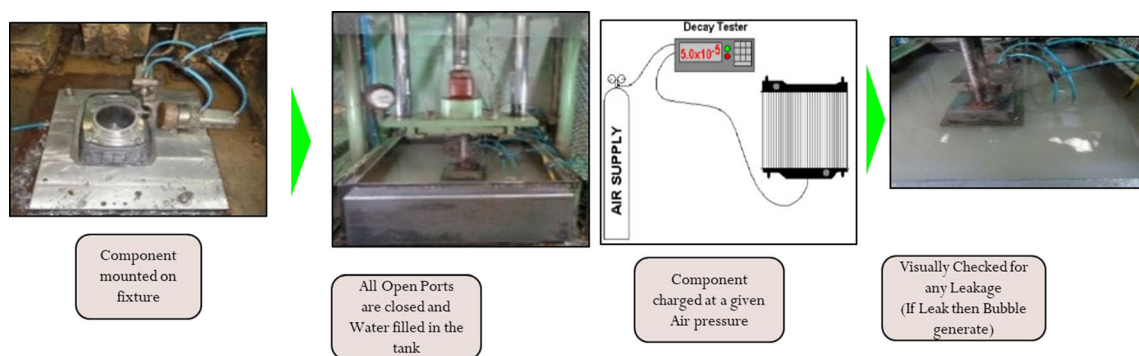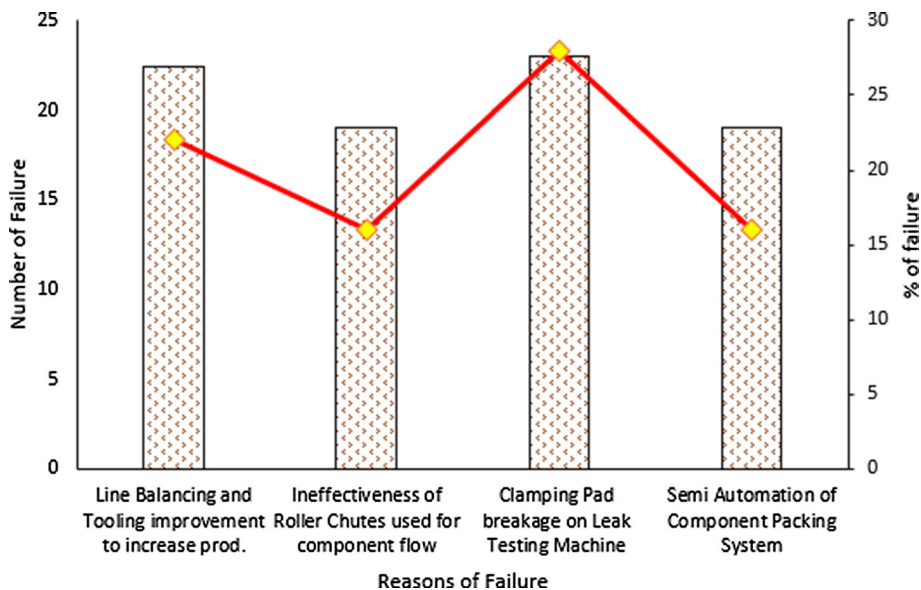
Table 1 K-T analysis

S. no.	Area of improvement	Pardeep			Raman			Ankur			Ashish			Rakesh			Team average			Total points
		S	U	G	S	U	G	S	U	G	S	U	G	S	U	G	S	U	G	
1	Line balancing and tooling improvement to increase prod.	5	9	8	9	9	8	6	9	10	5	6	7	8	7	6	**6.6**	**8**	**7.8**	**22.4**
2	Ineffectiveness of Roller Chutes used for component flow	6	5	6	7	5	7	8	5	6	7	5	8	7	5	5	**7**	**5**	**6**	**18**
3	Clamping pad breakage on leak testing machine	9	8	7	8	8	6	7	7	8	8	9	7	8	9	7	**8**	**9**	**7**	**23**
4	Semi-automation of component packing system	6	7	7	6	5	7	5	7	5	5	5	5	7	7	8	**5**	**6**	**7**	**18**

Bold values indicate team average and final points for different area of improvements

However, during the process, it was found that the effectiveness of the leak testing machine has been reduced due to the enhanced number of rejections in final testing of components (cylinder block). The problem detected in the leak testing process may have been raised due to the imperfection and failure of the leak testing machine. Thus, to identify the area of failure and its root cause a Kepner-Tregoe (KT) method is employed. The KT method is beneficial in identifying and detecting various existing problems and prioritized their solution in an iterative way at manufacturing line and in leak testing machine.

The Kepner-Tregoe (KT) Method

The KT method is a practical and structured methodology used for decision-making, identifying problems, and determining potential risks. It identifies the concerns by listing them one by one followed by bifurcating the level of concern and defined them in terms of the three dimensions listed below [6]. The KT method is one of the multiple thinking domain approaches being used by several manufacturing sectors and thus is an area focused on several researchers [7]. It is one of the clear thinking practices to secure a competitive advantage over others that further helps to flourish as a strategically aligned organization.

Urgency It is the gravity level of the problem and related to the urgency of the time needed to resolve the problem.

Seriousness It is the seriousness level of a problem and related to the impact of the problem to the organization.

Growth It is related to the growth of problems. The faster the problem develops, the higher the growth rate will be.

Based on these dimensions, individual can evaluate that one concern which is relatively more important than another and consequently should be addressed first. In K-T methodology, four rational processes are considered which reflect four fundamental questions that help in making the decision methodologically and effectively. The present work adopts the same by bifurcating four rational processes of the KT method one by one.

Situation Analysis (Outlines Concern)

There is imperfection in leak testing process during performing bubble leak testing of cylinder block.

Problem Analysis (Problem Identification and Root Cause Determination)

For problem identification and analysis, a quality circle team constituted various stakeholder's departments, i.e.

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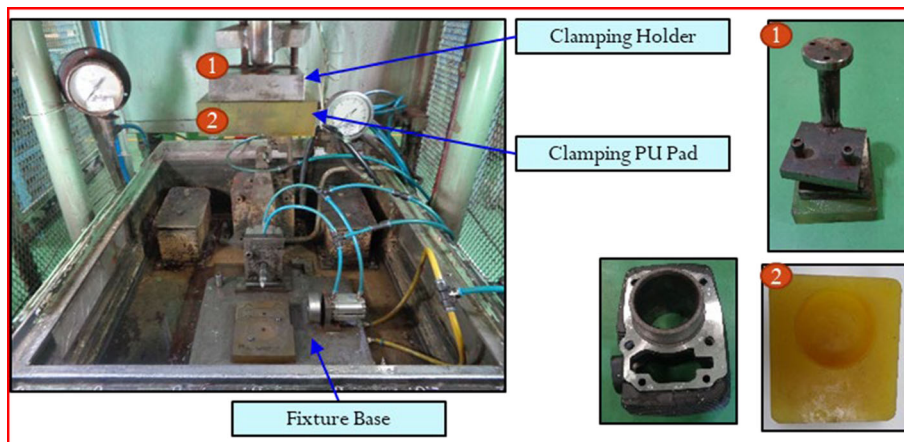J Fail. Anal. and Preven. (2020) 20:1507–1515

production department, quality assurance, and materials department. Quality circles (QCs) remain feasible and continue to operate effectively [8]. In quality circle team, various stakeholders from different departments are selected and employed seven quality tools to identify possible causes and remedial actions. Various QC tools were employed to identify root causes. An average 4-month rejection of 74 cylinder block components is considered. The multi-variate plot is developed using the data of the number of rejections based on different concerns, obtained from manufacturing division. Figure 2 shows the bar chart for the same representing different reasons with ease. Table 1 reports the detailed analysis of the QC team in detecting the problem by giving a problem ranking on scale from 1 to 10 as seriousness, urgency, and growth.

Based on the knowledge and experience of experts and workers, four important regions are selected for checking and further improvement, the line balancing and clamping pad breakage. From Fig. 2 and Table 1, it is evident that significant rejection is primarily because of the clamping pad breakage and poor line balancing that needs tooling improvement. The former reason can be dealt with K-T analysis as the latter concern can be dealt on production line itself. Based on the problem analysis, it becomes evident that breaking of clamping pad on leak testing machine has higher points as compared to other area. Therefore, the problem of clamping pad should be considered first, and further analysis must be performed.

The QC team brainstormed and come up with root cause of clamping pad breakage in a leak testing machine and their probable solutions. During the engine cylinder block clamping process, two crucial components in fixture play important role in holding and stabilizing the component (see Fig. 3).

1. Clamping holder.
2. Clamping PU pad.

After close look at the clamping pad part, it was clearly seen that cracks were generating as depicted in Fig. 4. While using this fixture and clamping pad during manufacturing and testing of cylindrical block, generated cracks at clamping pad were leading to imperfection in cylindrical block which was the primary reason for leakage testing failure. From further analysis, it was also realized that three different types of clamping pads are being used during the leak testing process for the effective results, leading to cost and time wastage in changing as per the different model. The problems and the adverse effects concerning these issues are explained in Table 2.

Based on the defined problem above, data were analysed over a period of time and it was observed that there were two reasons for clamping pad change. Either cracks were generated or there was need to change clamp pad because of wear. To compare both reasons, quantitatively data through check sheet were collected and analysed (see Table 3). From Table 3, it is evident that most (75%) of the clamping pads were changed due to the crack generation and less (only 25%) due to wear of the pads.
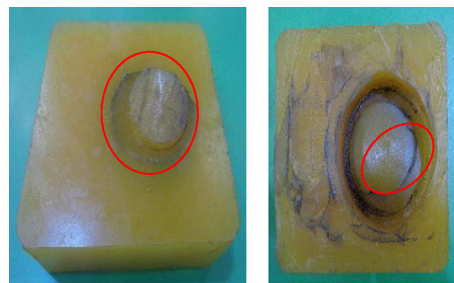

Fig. 4 Generated crack at clamping pad

Fig. 3 Component clamping fixture

Table 2 Problem definition and their impact

S. no	Issues	Results
1	Crack generation on the clamping pad	Affect leakage testing judgement since it is visual testing method
2	Different types of clamping pads are used for different models	Setup change = Time increase
		More Pad = More cost
3	Clamping pad replacement	Total cost = Rs. 6980
4	Clamping pad rotates. So, need to be adjusted	Operator fatigue

Table 3 Data analysis for pads replacement

No. of pad change on monthly basis					
Month Pad change reason	Apr-19	May-19	June-19	July-19	Total
Crack generated	11	13	15	17	56 (75%)
Wear out	4	2	5	7	18 (25%)

Table 4 Objectives formulation based on above analysis

S. no.	Criteria	Before	Now
1	Clamping pad (PU) replacement/year	24	6
2	Different types of clamping pad used for different models	3 Type	01 Type
3	Operator Fatigue	High	Low

Decision Analysis (Objectives are Identified Against Potential Problems)

Based on the quantitative analysis in Table 3, three objectives were set and are tabulated in Table 4 based on the problem definition. The first objective was reduction in clamping pad replacement per year. Since, wearing is natural phenomenon that is not easy to forbid; therefore, we only focused on reducing clamping pad breakage to zero. During clamping process, three different types of clamping pad were used based on different models. Objective are set to design new clamping pads which can be used for different models, thus, reducing the cost and changeover time.

Failure Analysis To identify root cause for crack generation in clamping pad, QC tool like cause and effect diagram is used. Figure 5 shows the cause and effect diagram prepared by quality circle team that sits together and by rigorous brainstorming under the four factors (man, machine, method, and material), and all probable causes are listed that may lead to crack generation and thus result in rejection of parts. Table 5 provides the inspection report for improper fitment, while, Table 6 shows the comparison between existing and new design.

Validation of Probable Cause

In the cause and effect diagram, the QC team lists all possible reasons which may have led to crack generation. It is indispensable to test and validate these probable causes. We selected each of the listed probable cause and verified at the manufacturing line.

1. *Man* To check improper fitment, sample of five cylindrical blocks are selected from various shifts in which different workers were performing their job. It was found that there were no issues detected with any improper fitment. Therefore, no counter measure is needed for this listed probable cause.

2. *Machine* Two probable causes were selected for validation.

(a) *High clamping pressure by machine* It was found that pressure at which machine working was within the specified range of 1.5–3 kg/cm^2, so no counter measure is needed.

(b) *Clamping arrangement design* In clamping arrangement design at fixture, there was no side support available to clamping pad due to which clamping
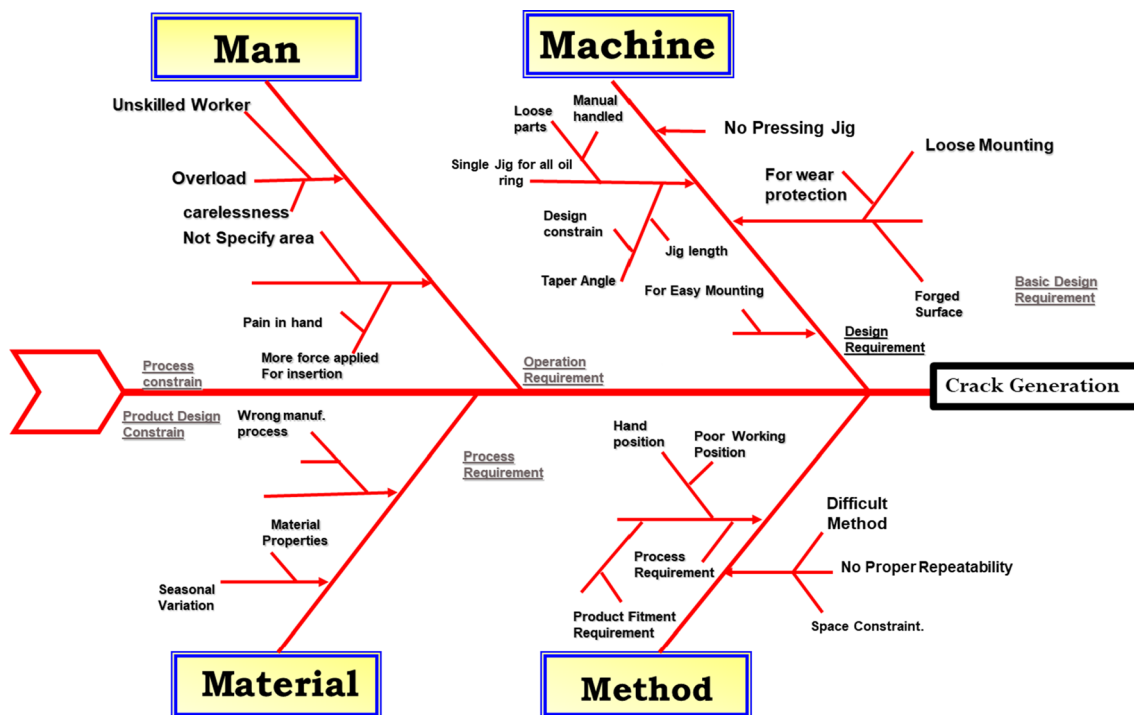
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Fig. 5 Cause and effect diagram for validation of probable cause

Table 5 Checking report for improper fitment

S. no.	Production shift	Line	Sample size	Fitment
1	Morning	1	5	Found OK
2	Morning	2	5	Found OK
3	Evening	1	5	Found OK
4	Evening	2	5	Found OK

pad rotates most of the times during clamping process. Thus, a counter measure is needed to rectify this crucial problem.

3. *Method* In method, it was checked whether the load applied by fixture on the clamping pad is even or not throughout the surface. Due to non-alignment of line of action, force by machine and axis of clamping pad alignment was not proper (see Fig. 6). Hence, counter measure was needed for this cause.

4. *Material* Material of clamping pad was soft with hardness of 60 BHN. To counter this probable cause, material change was needed.

Therefore, after thorough investigation and analysis, it was found that there are mainly three regions where a remedial counter measure is required to prohibit the mode of crack generation and thus failure of the process. Figure 7 clearly illustrates the process flow beginning with defining problem, their causes, essential checks, analysis, and results.

Action Identification and Implementation (Actions Proposed to Minimize Risk/Problem)

Countermeasure 1 In clamping arrangement design, due to unavailability of side support, there was not proper fitment. After brain storming, a new design concept was developed which may provide side support and proper fitment. A 3D concept developed to visualize the idea.

Countermeasure 2 In the second counter measure, developed 3D concept was lacking side support and there was a blind hole in PU pad. In the suggested counter-measure, side support was provided in the concept and through hole was generated at the place of blind hole in PU pad as depicted in Fig. 8.

Countermeasure 3 The soft PU material replaced with hard material having BHN 80 instead of 60.

Effectiveness of Actions Implemented

After implementation of new clamping pad with hard PU material, it reduced clamping pad replacement per year from 24 to 6 (see Fig. 9). At the place of three different types of clamp pad, our new design was serving purpose of all which not only beneficial in terms of monetary benefit

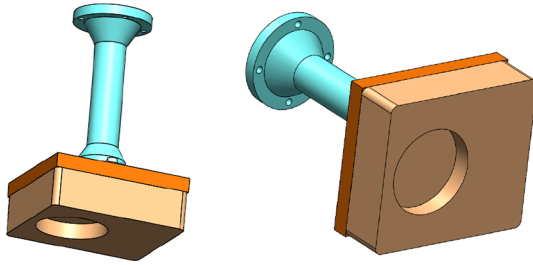**Table 6** Comparison of existing method with new design

Before (Eccentric Holder)	After (Centric Holder)
An external load whose line of action is parallel but does not coincide with the centroidal axis of machine component	An external load whose line of action is parallel as well as coincide with the centroidal axis of machine component

Fig. 6 Eccentric load at fixture

but also helps in reducing operator fatigue which was a non-tangible benefit. Data collected over a period of four months from September 2019 to December 2019. There was drastic reduction in rejection after the implementation of identified actions. Rejection rate is reduced by 90% (from 74 to 8) as reported in Table 7. The clamping pad change percentage is reduced significantly by 95%, and pad change due to wear and tear also reduced considerably due to use of hard PU material. Figure 10 shows the comparison of the number of clamping pad replacement before and after implementing suggestive measures. It is worth mentioning that reduction in clamping pad rejection due to

crack generation and further failure of leak testing machine has been narrowed down with the help of K-T analysis in this study. Furthermore, cost analysis of implemented solution shows that it is a viable solution.

Standardization

Developing standards for drawings and designs are an essential step for any industrial organization. With proper definition and implementation of standards, defects or failures can be prohibited in production line and at the same time constitute procedures to prevent the occurrence of other errors that could have an impact on production. It is therefore desirable to standardize all processes carried out in the manufacturing sector [3]. After successful trial of clamping pad on fixtures, standardization was done by allotting engineering drawing part code. The standardized clamping and fixture parts are shown in Fig. 11 that can be directly fed to a manufacturing line of any industry and will perform effectively and efficiently in a leak testing process.

Conclusions

This article presents a new approach for investigating the problem of clamping pad failure leading to rejection of cylinder block during leak testing process. The failure analysis is carried out to understand the root cause of failure. The Kepner-Tregoe analysis is adopted to solve the problem and suggest preventive measures. It gives a benefit in solving even those problems which are not visible and creating hindrance. The problem detected is mainly the

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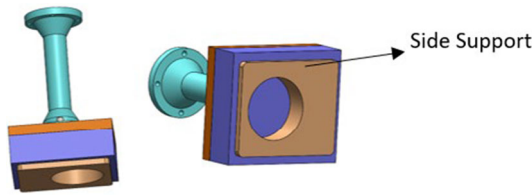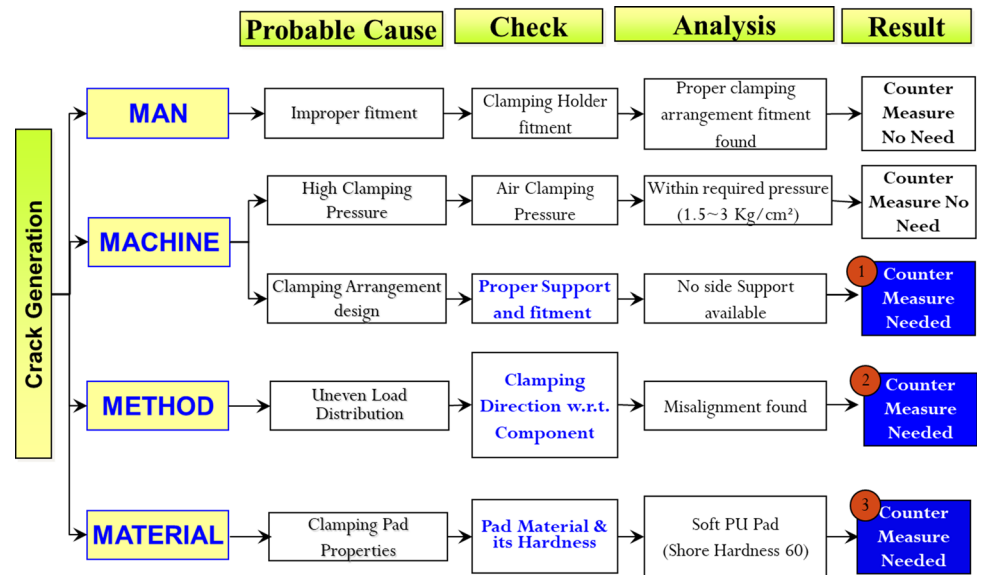**Fig. 7** Validation of probable causes

Fig. 8 Modified 3D concept

crack generation in clamping pad resulting in failure to hold the part during leak testing process and that lead to rejection of parts in further testing. The step-by-step methodology suggested appropriate preventive actions that successfully reduced the clamping pad replacement by 90% during leak testing process. This method of problem selection at manufacturing line is unique, and problem selection is coming from workers who are working at manufacturing line. The whole approach was unique and

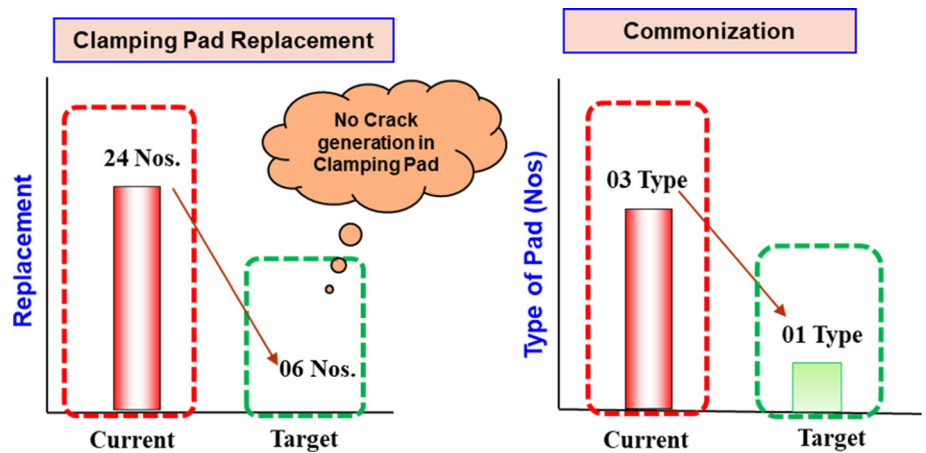**Fig. 9** Before and after change once necessary actions implemented

Table 7 Testing of pad change after corrective action

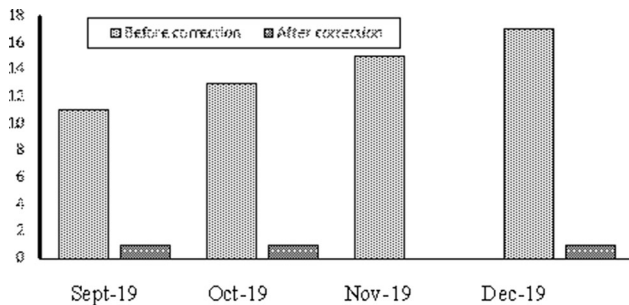| No. of pad change on monthly basis					
Month Pad change reason	Sept-19	Oct-19	Nov-19	Dec-19	Percentage reduction (%)
Crack generated	1	0	0	1	95
Wear out	1	2	2	1	66

Fig. 10 Reduction in failure of clamping pad after implementing corrective measures
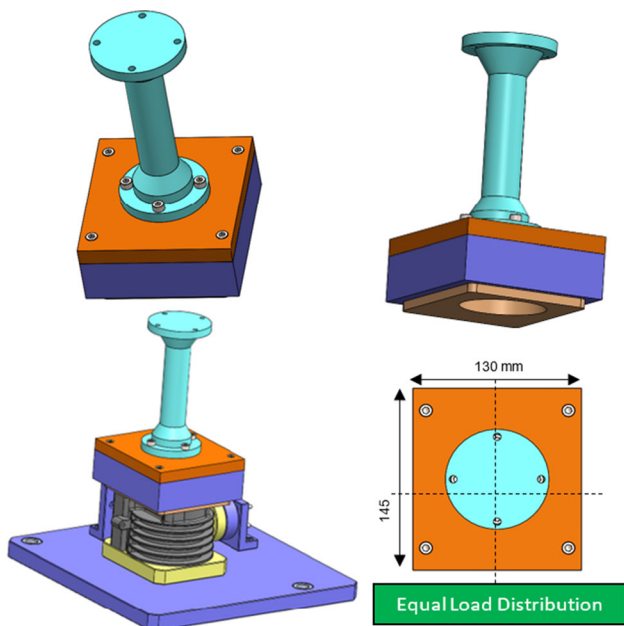

Fig. 11 Final standardized 3D concept

easy to adopt which can be implemented in different domains in manufacturing sector to prevent any such problems and issues from continuing to a great extent and thus can improve their services effectively.

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