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RELIABILITY IMPROVEMENT METHODOLOGY FOR CONSUMER PRODUCTS - A CASE STUDY

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Abstract- The objective of every industry is to bring world-class quality products to the market in shortest possible time with least expenses. To meet this objective manufacturer's always remains non compliant with Reliability requirement of the products due to which field failure rate increases and in turn increases the warranty cost. In this work, an attempt has been made to improve the field reliability for consumer product through a proposed step by step Reliability Improvement Methodology. The proposed methodology includes analysis of field failure data, failure analysis for identifying root cause, experimental investigation to confirm root causes, design modification recommendations and improvement validation through accelerated testing. Further, this analysis helps the manufacturers in warranty extension decision making for the existing products and in the improvement of the next generation product's performance which directly increases the brand image and profits of an organization.

Keywords- *Product Reliability, Weibull analysis, Failure analysis, accelerated testing.*

I. INTRODUCTION

Today's demand for reliability on products and manufacturing processes with lower cost is continually growing, with customer becoming more demanding and informed, especially in consumer products. With the increase of competitiveness in the global market, manufacturers are extending their warranty period in order to bring more customers to their brand. Therefore, it becomes necessary to develop methods to understand the field behavior of products and to estimate their field reliability.

Before any reliability improvement can be made to a product it is necessary to assess the current reliability of the product in the field. This can be achieved by collecting field failure information throughout a products' life and performing analysis on the collected data. Therefore, the most challenging aspect of product quality and reliability data analysis is often the acquisition and management of the data itself. Many organizations are unable to take advantage of valuable field product-failure or field performance data due to the variety of reasons, e.g., data is not collected, the data lacks uniformity or sufficient granularity and/or the data is inaccurate or lacks validity. If the data is collected at all, it is often stored in a variety of locations (manufacturing sites, repair centers, in-house testing facilities, telephone call centers, etc.) with little or no integration among data sources or uniformity in format. These deficiencies in the data infrastructure make a coherent analysis difficult or impossible. Therefore, an integrated approach should always focus on assuring proper collection of that data in some appropriate format, its storage and analysis to present it in such a way that can facilitate its use in a meaningful manner. Such an approach will lead to a complete Product Quality,

Reliability Analysis and Reporting System that allows an organization to turn real-time data into information, and information into decisions for rapid continuous improvement.

Over the years, the adoption of this reliability philosophy for business has led Crompton Greaves Ltd (CGL), to develop and implement an automated system for tracking product field reliability. The creation of such a system for CGL is "Service Operations Management Application" (SOMA), involved the modification and integration of many individual systems and disparate data sources. The SOMA is a comprehensive and automated system that incorporates all facets of data acquisition, coupled with advanced reliability analysis engines to provide real-time data and reliability predictions for CGL products worldwide, in a comprehensive and easy-to-use graphical format

In this study, "Table Fan" as a consumer product is selected for reliability improvement analysis. Table fan product performance data has been collected from the centralized database, SOMA. This data has been organized to estimate the current reliability by performing Weibull analysis.

This also gives an idea regarding the products life cycle phase. Failure analysis on the field failed samples is conducted to identify sub systems/components and their failure modes, which are Critical to Reliability (CTR). To validate identified failure causes / modes for product unreliability, experiments have been conducted. As a result, design/manufacturing processes modifications were recommended for reliability improvement. Reliability improvement verification has been done using accelerated testing after incorporating the recommendations in required number of samples.

II. PROPOSED METHODOLOGY FOR RELIABILITY IMPROVEMENT ANALYSIS

The method proposed for reliability improvement analysis based on failures reported during warranty period is shown in Fig.1 followed by the description of each steps in ensuing paragraphs.

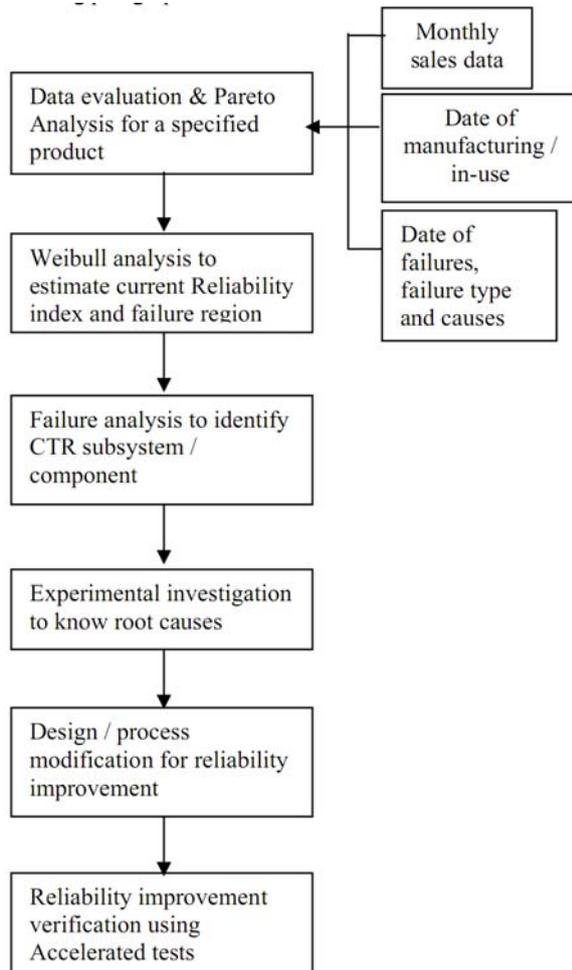


Fig. 1 Proposed Reliability Improvement Analysis Method

Methodology Description

1. The first step in the proposed method involves the evaluation of the first failure for each sold product in a given period of time, usually set equal to or greater than the pre-defined warranty period. Based on the failures reports a time to failure database was developed. Those reports present the product in-use date and the date where the costumers reported the product first failure. After data collection and evaluation, it becomes necessary to find which defect/failure needs to be investigated first since a product has too many failures. For example, a table fan has many failures like motor failures, blade failures, oscillation defects etc. This can be done using "Pareto Analysis" to prioritize the type of defects/failures to be attacked first based on its highest failure rate.

2. The second step in the methodology i.e., Weibull analysis needs to be performed to assess the current product reliability before doing any reliability improvement and to identify the failure region of the products life cycle.
3. The third step in the methodology involves failure analysis, which is a scientific investigation of a series of field failed samples for the following purposes:
 - To get valuable information from the field returns such as number of defects, the type of defects, and root causes etc.
 - To identify the Critical to Reliability (CTR) subsystem/component causing for product unreliability
 - This analysis is also utilized to identify failure mechanisms as the first step in developing accelerated stress tests.
4. The fourth step in the methodology involves validating the identified failure modes through experimental investigation i.e., testing for failure modes through simulating the actual field conditions in the laboratory to know the exact root causes for a particular type of defect.
5. The next step in the methodology is to provide alternate solutions to make the product robust based on the identified root causes. This will involve making necessary changes in the current product design / processes for reliability improvement.
6. The final step in the methodology involves performing accelerated tests on the prototypes made as per recommendations for validating reliability improvement

III. RELIABILITY IMPROVEMENT OF TABLE FAN-A CASE STUDY

Step 1: Data evaluation & Pareto Analysis

A table fan is one of the ubiquitous common electric appliances used in houses, offices, shops and business establishments to provide air circulation and to cool down temperature. Fan circulates air, which enhances the evaporation rate of sweat from body, due to which body is cooled. Table fan product life data has been collected for about 2 years from the CGL centralized database, SOMA. Since Table fan field failure data involves many component defects/failures such as motor, shaft, blades, oscillation etc., it becomes necessary to perform a Pareto analysis in order to identify the major defect. A Pareto chart of table fan defects is as shown in Fig.2. From the analysis it is found that oscillation defects are contributing 75% of failures. Therefore, table fan Gearbox is selected for the Reliability study in order to study the oscillation

mechanism failures/defects i.e., either jerky oscillation or no oscillation.

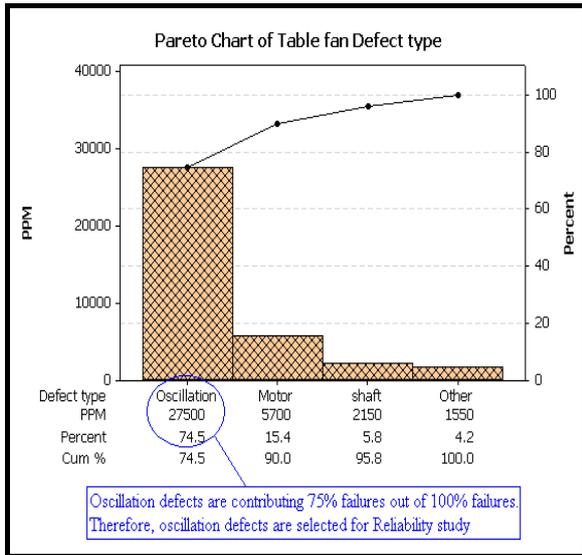


Fig.2. Table fan defects Pareto Chart

Table Fan Gearbox:

An oscillating fan cools an area using forced convection thus increasing heat transfer. This is accomplished by spinning three plastic blades which circulates air in the desired direction. The blades are spun by an AC motor, which is powered from a standard source wall outlet. The fan is also capable of horizontal oscillation. The user can start this movement by pushing a button at the top of the fan casing, which in turn engages a gear train which spins a small linkage. This linkage is connected to a bar attached to the casing. This simple mechanism translates circular motion to oscillatory horizontal motion. The gear train is powered by the same motor and shaft that spin the blades, thus slowing the speed of the blades, but not requiring an additional motor. The Fig. 3 represents Gearbox of a Table fan.

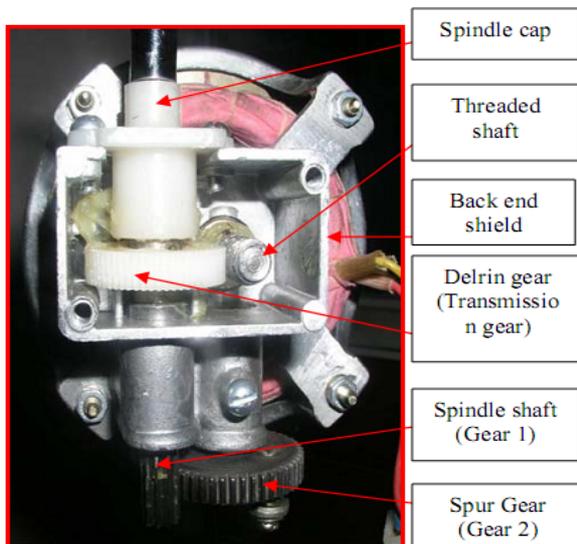


Figure 3: Table Fan Gear Box Components

Step 2: Weibull analysis

In life data analysis, the analyst attempts to make predictions about the life of products in the population by "fitting" a statistical distribution to life data from a representative sample of units. The parameterized distribution for the data set can then be used to estimate important life characteristics of the product such as reliability or probability of failure at a specific time, the mean life for the product and failure rate.

The collected field failure data has been organized in Nevada format to calculate the current reliability of table fan (A piece of life data in Nevada format is shown in Table 1). In Table 1, the left column shows the month of manufacturing and top row shows the month of return. For example, 20608 Table fans have been sold in the month of Mar 2009, in which 39 table fans have been returned in May 2009.

Life data	Dec 08	Jan 09	Feb 09	Mar 09	Apr 09	May 09	Jun 09	Jul 09	Aug 09	Sep 09	Oct 09
Dec 08	7348	0	0	2	3	12	1	0	3	2	1
Jan 09	2285	0	0	2	2	11	4	4	3	0	1
Feb 09	11534	0	0	11	29	13	9	5	11	2	
Mar 09	20608	0	0	11	39	13	13	14	4	7	
Apr 09	17061	0	0	2	37	11	14	20	11	5	
May 09	19619	0	0	0	4	13	22	14	17	9	
Jun 09	15555	0	0	0	1	17	17	14	5		
Jul 09	11936	0	0	0	0	0	1	1	3	3	
Aug 09	5692	0	0	0	0	0	0	0	1	2	
Sep 09	3415	0	0	0	0	0	0	0	0	1	

Table 1: A piece of Table Fan life data converted in Nevada format

Weibull distribution has been suited as best and suitable model for this life data among various other distribution models. Weibull analysis has been conducted for analyzing the product life data using a reliability tool (Weibull ++ 7.0). The graphical representation of the analysis i.e., Reliability Vs Time is shown in Fig. 4.



Figure 4: Reliability vs. Time plot of Table fan life data analysis

The above graph shows Reliability index as 0.974 at the end of 2 years and the estimated parameters of the Weibull distribution are as $\beta=0.895$, $\eta=1425$ months. Since the shape parameter β is less than 1, it indicates that the product is in the early failure phase of the product's life cycle. The early failure region indicates the various reasons for product failure such as manufacturing process, processes tolerances etc which needs to be investigated.

Step 3: Failure analysis

One of the major reasons identified for Table Fan unreliability is failure of the Oscillation mechanism under normal working conditions. To investigate the jerky oscillation problem, field failed samples & one year old table fans under working condition are collected from field and discussions were held with multi-disciplinary team to analyze the defects. From the defect analysis, it is observed that

- Wear out of delrin gear observed in all the samples. On further investigation, an axial play of delrin gear is also observed. This axial play is causing wobbling of delrin gear which may leads to start jerky oscillation leading to delrin gear worn out, i.e., an Issue related to the aging.
- Loose alignment is observed between delrin gear ID and spindle shaft OD in some samples, i.e., Issue related to fits & tolerances
- Burrs / threaded chips were present in the grease pasted between the delrin gear and threaded shaft in few failed samples implying an Issue related to manufacturing process.

As a result, the CTR component such as delrin gear (plastic gear), spindle shaft and threaded shaft (worm gear) in the Table Fan Gear box were selected for Reliability Improvement study.

Step 4: Experimental Investigation:

To validate the above identified root causes for oscillation defects, prototypes were made in the following category as listed below and same were tested under normal operating conditions to study the field failures.

- Existing Product to see issues related to aging – No Failure occurred but slight uniform wear observed on Delrin gear tooth.
- Prototype made by worst case tolerances – Failure was observed after 25 days of continuous operation of table fan
- Prototype made by inducing burrs between rotor shaft and Delrin gear – No Failure occurred but slight non-uniform wear observed on delrin gear tooth.

From the above testing and failure analysis, it is concluded and recommended that,

- Reducing the axial play of delrin gear for proper defect free oscillatory motion.
- Tolerance stack analysis of table fan gear box needs to be performed for proper gear

engagements such as clearance between spindle shaft and delrin gear, center to center distance between spindle shaft and threaded shaft.

- Improving the manufacturing process of thread rolling against the burrs removal.

Step5: Design modifications for Reliability improvement

The following appropriate modification has done on the current design to avoid the above issues.

1. Existing design was modified such as
 - Minimum axial play of delrin gear was achieved through increasing the width of the delrin gear with slight modifications in spindle cap design.
 - A complete tolerance analysis is carried out on gear box for proper gear engagements. As a result, clearance between spindle shaft and delrin gear is made to reduce by 50%.
2. Necessary actions were taken in manufacturing process to avoid the entering of sharp edge burrs between gear engagements

Step 6: Reliability improvement verification using Accelerated tests

• **Test Execution:**

1. In order to validate the recommendations in reliability improvement, reliability testing was performed on prototypes made as per the suggested improvements to check the performance of the product over a period of time with at least one test sample fail due to oscillation defect.
2. Test Cycle plan
5 samples were planned to be tested for worst conditions under the different stress levels as shown in Table 2 and the test profile of the same is shown in Fig.6.

Steps	Combined Stresses		Duration
	Voltage (Volts)	Switching (min)	
1	140	10 min on & 2 min off	30
2	210	10 min on & 2 min off	30
3	270	10 min on & 2 min off	30
Total duration to complete one cycle			90
No. of samples under testing			5

Table 1: Accelerated Test Cycle

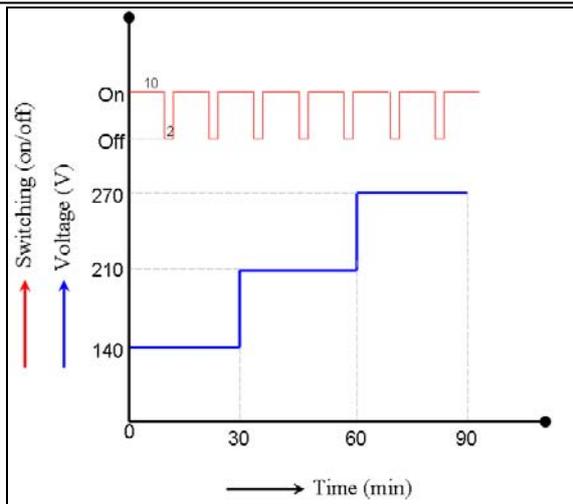


Fig. 5 Test Profile (Time vs. Voltage & switching)

3. Failure criteria:

At least one sample out of 5, should fail to perform its function i.e., oscillation defect.

4. Test Setup

Test set up is developed to perform the above the Test cycle as shown in Fig. 6



Fig. 6 Test set up developed for the execution of above test cycle

• **Test Results:**

Reliability testing was carried out for 50 days of continual operation under different accelerated stress levels in order to validate the recommendations. The test results of improvement are shown in Fig. 7. From the testing it is confirmed that there is no oscillation defect found in any of the samples tested.

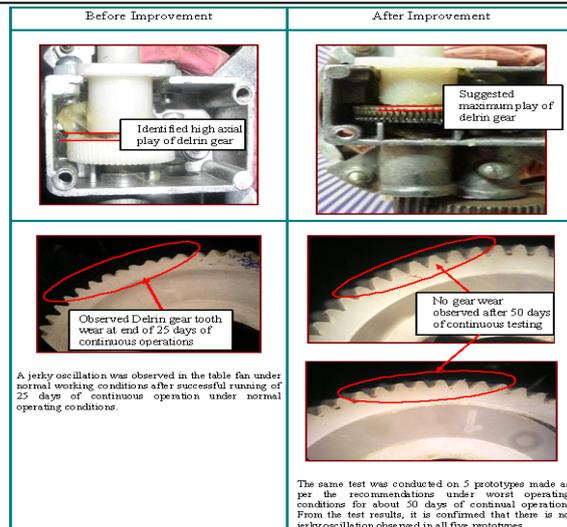


Fig. 7 Test Results before and after improvement

IV. CONCLUSION

The proposed analysis facilitate the manufacturers to assess and improve the useful life of the existing product and also, helps manufacturers in the improvement of the next generation product's performance, which in turn increases the brand image as well as profits of the company. In this paper, a methodology for reliability Improvement of consumer product has been proposed. The proposed methodology has been successfully applied to consumer products and is presented in detail by taking ubiquitous "Table fan" as a case study. Through design modification, the approach has been validated and verified on the identified critical item-Delrin gear and mitigation of its associated failure mode- gear wear out.

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