

Good Practices for Handling and Investigating Failed Components

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1 Introduction

The purpose of this good practices document is to help improve reliability and survivability of marine energy converters, through improved information collection, analysis and dissemination when components fail.

The marine industry is focused on eliminating these failures through better understanding of the how and why they fail and there is a need to capture these failures as they happen, in order to provide a better understanding of their causes. This guide provides a systematic approach to handling, securing, sampling and conducting an initial investigation into failed components prior to submitting them to an appropriate team for analysis.

This guide is to be used by a developer or marine contractor conducting onshore and offshore device operations, including transporting, lifting, installing, deployment, testing, retrieval, and maintenance operations, during which a component could potentially fail.

The guide describes how to handle, package and investigate a failed component. It includes a description of the conditions in which failures occur, a suggested taxonomy for classification (produced by the AFRC, 2015), a handling process, and an initial investigation using Root Cause Analysis (RCA). Appendix 1 provides a proforma to collect useful information relating to the failed component. The proforma has been designed to be used across the industry, both nationally and internationally.

This guidance has been developed with reference to many well established and recognised methodologies in the reliability industry (FMEA-FMECA, 2016; Andersen & Fagerhaug, 2006; MoD, 1995). The aim in following this guidance is to establish a culture of reliability, whereby failures initiate a proactive risk assessment approach that underpins and supports design, manufacturing, and predictive O&M.

2 Background

The Offshore Renewable Energy Catapult (ORE Catapult) commissioned EMEC to undertake a year-long wave and tidal industry project with the aim to identify and retrieve failed components for analysis. Through a dedicated industry workshop, critical insight into the cause of device component failure modes were obtained and discussed concluding with a pilot investigation of a number of components. EMEC, the Advanced Forming Research Centre (AFRC) and Brunel University provided a structured testing programme, whereby developers could submit their failed components to the testing laboratory for analysis. The outcome for the project was to create an online database, so that failures are recorded and analysed for industry learning. A case study based on the results of the component analysis has been published¹.

¹ ORE Catapult, Marine Energy Component Analysis - Case Study, PN78-SRT-001 Rev 0, July 2016 available from ORE Catapult

As a regulatory requirement, it is necessary for developers to have an independent Third Party Verification (TPV)² conducted on the detailed device design and foundation/mooring system for the conditions expected at the deployment site. However, unexpected component failures have the potential for both costly and catastrophic events to occur when components ultimately fail. EMEC has found that a number of small failures could lead to a catastrophic event occurring and thus there is need to capture these failures, report and analyses for the benefit of the sector. Recording failure events as soon as it is safe and available to do so in marine operations is imperative.

Once the failed component has been isolated, it is essential there are defined steps to handling and investigating. As the results of analysis provide cause to those failures, we can create and develop a feedback loop of common failed components stored and available to industry on a database developed and hosted by the ORE Catapult.

3 Approach to preservation and handling

3.1 Introduction

The proper handling and preservation of failed components prior to analysis is important [AFRC, 2015]. If the component is not properly handled, important information may be destroyed, or obscured, introducing uncertainty into the analytical results. The suggested steps to preserve and handle components are presented below.

3.2 Isolate the site of failure

Once a failed component has been identified, and depending on its location in the system, the task at hand is to separate it from the system or subsystem without causing subsequent failures within an integrated system.

- Section off areas or select samples for analysis that are representative of the failure mode as described in Table 1, Appendix 1.
- Take photographs to document the site of failure.

3.3 Maintain components' integrity

Sample preservation is one of the most important aspects of a failure investigation. Care should be taken to provide the failure analyst with a sample in the best possible condition to allow the most accurate assessment of the failure scenario. Ensure failed components are handled so that handling does not influence the measurements to be made. If a section of the component must be cut or removed from a larger piece, care must be taken not to contaminate or alter the area of interest. For example, scraping on a hard surface with a metal instrument can produce wear debris from the instrument which may add to the component surface or collect as surface deposits.

² A TPV is a report that certifies the integrity of the structural design of the infrastructure for the conditions. The report must be provided by an independent accredited agency of recognised international standing and reputation.

It is important to start documenting the component by photographing the site of failure from as many angles as possible.

- Photographs should be taken prior to handling the component.
- Handling of failed components should be kept to a minimum.

3.4 Avoid touching

Fingers can host organic and inorganic compounds that can contaminate the failure site. Fingers can also inadvertently remove important deposits from the component surface. If you have to use your hands, use gloves. Smaller component samples can be handled with tools such as tweezers. Beware when handling failed electronic equipment and the associated risks of electrostatic discharge.

- Keeping handling to a minimum. Poking, prodding or scratching with tools or instruments should be avoided.
- Keep all synthetic material away from electronic equipment such as printed circuit boards and wear an electrostatic wrist strap when handling.

3.5 Preserve the sample

First contact the analytical laboratory to determine the appropriate sample size. It is important to preserve the sample in a way that prevents potential changes to the failed component morphology and/or composition between time of the sampling and analysis. Oxidation, evaporation, chemical interactions may occur if the sample is not properly preserved.

- Collect, package and store the component in a clean or new container.
- Avoid tape as it may leave an adhesive residue or could remove critical material from the component
- If the sample is then to be shipped, package it in such a way as to limit contamination or physical damage.
- Identify and label the container and clearly mark its contents.

Provide additional information such as where the failed component was from, what it was used for, the environmental conditions that it was exposed to, size, weight, and if possible indicate the area of interest with a diagram rather than marking on the component.

Appendix 1 provides an example of the standard information required when submitting a component for analysis.

EMEC recently preserved tiles exposed to biofouling by vacuum packing the tile. The tile and biofouling samples were preserved without exposure to air, liquids or other potential contaminants.

3.6 Provide a control sample

As discussed above, it is beneficial to the analysis if a representative counterpart of the failed component can be provided alongside the failed component to be used as a baseline for comparison. The control sample must not have failed and does not necessarily need to have undergone the same testing as the failed component. The control can help identify, for example, whether the failure was due to the incorrect specification or inappropriate use of the component. It is important to ensure the control sample, i.e. the bolt, was from the same manufacturing batch (e.g. same heat treatment, etc.) in order to be a true control sample.

- If you were presenting an unknown contamination, such as biofouling, submit suspected sources of contamination along with the unknown for comparison.

4 Method of Recording

4.1 Introduction

The reporter of the failed component should create a record and initiate an investigation to support the laboratory analysis. Appendix 1 includes a report template that can be used to capture the details of the failure incident.

- Ensure you have as many of the component and failure incident details as possible before you make an initial assessment of the failure modes.

4.2 Request information from suppliers

Prior to sending the failed component away for further investigation, it is necessary to request further information regarding the component from the supplier. This information should include: manufacture and testing records, inspection records, batch numbers and assembly records. In addition to this information, a full specification of the component should be requested.

4.3 Failure modes

The taxonomy for failure modes developed by the AFRC, provides guidance for initial investigators to make an initial identification of the failure mode classification. The table in Appendix 1 can be used to tick the most appropriate mode or modes of failure.

For example, if a shackle has failed and the location of failure is the area where the bolt/pin is corroded. The failure modes could be a combination of 'Material' and 'Wear and Tear'. For instance, it could be classified as 'Material' whereby the alloy of the bolt chemically reacts against the different alloy of the shackle causing a corrosive action or; it could be classified as the 'Wear and Tear' mode whereby rapid corrosion of the bolt was due to the highly saline, highly oxygenated environment that the bolt was exposed to. The purpose of the taxonomy is to help in providing as much information for the laboratory analysis team as possible.

In addition to providing the failed component and recording/evidencing the relevant information, it is also useful to provide a representative sample (counterpart) that has not failed³. Such a sample can help provide evidence to aid identifying and determining its failure mode. As mentioned previously, it is essential that any control samples are from the same batch as the failed component to ensure that they have undergone the same manufacturing process.

4.4 Initial investigation

Providing background information about the failed component to the analytical laboratory is critical. By using the taxonomy classification provided in Table 1 in Appendix 1, to attempt to understand the failure mode you can assist the analytical laboratory in its analyses.

The Failure Incident Report form in Appendix 1, can be used to record the information necessary to allow the investigative team to undertake a robust investigation and complete a Root Cause Analysis (RCA). The investigative team should comprise: the reporter of the failed component (e.g. developer), the test analyst (testing house) and, if possible, a representative from the component supplier.

The collection of information based on the failure incident will help provide structure to a process of investigation.

4.5 Root Cause Analysis (RCA) (to be completed by investigative team)

RCA will be completed by the investigative team to understand what caused the failure to occur. RCA is a reactive tool and should be used when a failure incident has occurred.

It is important to note the definitions of Failure Mode versus Root Cause.

- Failure Mode: is what the equipment or component failed from e.g. corrosion fatigue
- Root Cause/s: is what caused the failure mode to occur

Why should we use RCA? By reporting and documenting both we can improve overall understanding of the failures, and reduce costs associated with those failures. Investigating the root cause should allow an understanding to be reached on what caused the failure and why. The inclusion of the supplier in gathering the component information and the failure analysis can prove vital in determining the reason for the failure.

The corrective action resulting from an RCA, describes what can be changed to prevent recurrence of the failure. A corrective action can be misguided if a full RCA has not been completed. RCA is a vital step in problem solving the failure. The value of RCA compared to the cost of the failure cannot be overemphasized enough.

When setting up an RCA investigation, a team approach is best and it is important that the team is involved in brainstorming the failure's root cause. The cause and effect diagram,

³ Such a counterpart does not necessarily have to undergo that same testing as the failed component.

commonly called fishbone diagram, is helpful in brainstorming and can be used to visually display the many potential causes of the failure.

The steps in RCA and how to use the fishbone diagram are as follows:

- Step 1 - Define the problem – use the Failure Incident Report (see Appendix 1)
- Step 2 - Collect data – use the Failure Incident Report
- Step 3 - Identify possible causal factors – use tools such as Fishbone Diagram, Failure Mode Taxonomy and Five Whys (ask why until you get to the root of the problem)
- Step 4 – Identify and categorize the root cause(s).
- Step 5 - Recommend and implement solutions – use of Failure Mode and Effects Analysis (FMEA)

The use of a fishbone diagram can help to organize your investigation into the types of causes: Physical, Human and Organizational. Figure 1 provides an example of a fishbone diagram that could be put to use in the RCA.

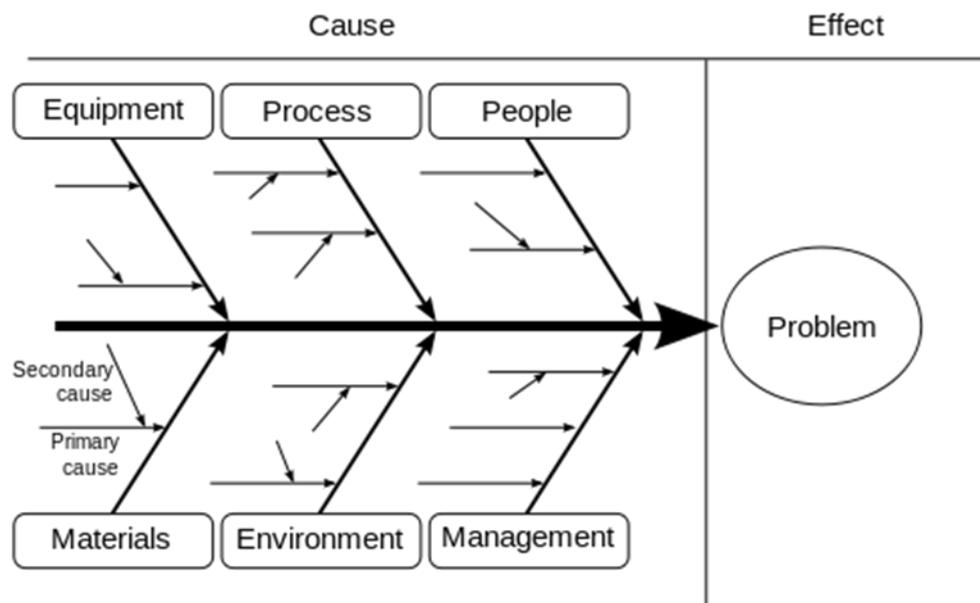


Figure 1 RCA Fishbone Diagram

4.6 Reporting

As discussed above, the creation and utilisation of the Failure Incident Report will provide not only the testing laboratories with vital information but should be supplied to the ORE Catapult to add to their component database⁴. This will allow it to be built into the component database for industry knowledge capture and dissemination. As a result, reliability performance metrics such as Mean Time Before Failure, Mean Time To Repair could be

⁴ Contact Simon Cheeseman via simon.cheeseman@ore.catapult.org.uk

determined for components and overall system. Thereby, informing and improving predictive O&M schedules and ultimately OPEX costs.

5 Action Summary

The following checklist of the actions described in this document will help to guide developers and other marine support personnel in collecting, handling, and initial investigation of a failed component:

- ✓ Isolate the sample.
- ✓ Photograph: Document the failure scene and failed component(s) with photographs, including wide angle, and zoom shots; remember you can never have enough photographs. If the failed part requires disassembly, capture this process through photography.
- ✓ Preserve: Remember - Don't touch anything. Avoid touching the sample or area of interest with bare hands. If you must use your hands, wear gloves and keep handling to a minimum. Look for secondary damage caused by the failure and document it.
- ✓ Do not clean the failed component.
- ✓ Do not try to fit mating fracture surfaces together.
- ✓ Choose samples that are representative of the failed component.
- ✓ Preserve the sample integrity; cutting fluids will contaminate a fracture surface and abusive sectioning will alter the prior heat treatment.
- ✓ Preserve the fracture surface; if two mating surfaces are in your possession, sectioning should only be performed through one of them, and only if necessary. Store these samples in clean containers.
- ✓ Avoid tape, as the adhesive may leave a film on the surfaces of the samples in contact with it.
- ✓ Clearly identify the containers with the part number, or other description of the component under investigation.
- ✓ Prepare: A listing of operating conditions and the manufacturing process background of the failed component should be made available to the failure analyst.
- ✓ Request further information from the component's supplier regarding the manufacturing and testing process, including batch number and full specifications of the component.
- ✓ Complete Failure Investigation Report and submit along with component.

Conclusion: Sample preservation is one of the most important aspects of a failure investigation, and care should be taken to provide the failure analyst with a sample in the best possible condition for accurate assessment of the failure scenario.

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Appendix 1 Failure Incident Report

Initial Incident Report to be completed by user of failed component or inspector of failed component.

FAILURE INCIDENT REPORT

Date of failure	
Time of failure (GMT)	
Duration of downtime (hrs:mins)	
Location of failure	

Incident description (<i>what happened?</i>)	
Occurred during:	Inspection Installation Testing Deployment Normal operations Retrieval Other?
Fault was:	Gradual Intermittent Sudden Continual
System was:	Unaffected Degraded Inoperative

Failed Item	System	Subsystem	Component
Description			
Usage from newly installed			
Usage since last repair/service or inspection			
Part/Asset Code; Serial Number or other identification number			
Was failed component packaged and handled correctly? Yes/No (<i>explain</i>)			
Has this component failed before? Yes/No (<i>explain</i>)			
Where consequential damage costs incurred? Yes/No (<i>explain</i>)			

Equipment History	
Is the service maintenance record available? Yes/No	
Date into service	
Date failed item fitted	
Date of last repair	

Environmental Conditions/Operating Conditions
--

What was external conditions at site?	Wave (Hs) Tide (Neap/Spring) Currents (m/s) Salinity (ppm)
What internal conditions was the component under?	Heat Friction Tension

INVESTIGATION

Failure Mode/s: *please specify, where possible, what are the likely failure modes (available in Table 1) perceived at this stage in the investigation*

Comments:

Reporter/Investigator Contact Details:

Handling and Preservation details:
Sent to:
Laboratory Contact Details:

Table 1 Failure modes taxonomy developed by AFRC

Failure Causes							
Design	Design concept error	Poor specification	Modification	Incorrect assumptions (operating conditions)	Incorrect assumptions (behavior)	Design for manufacture / assembly / repair / maintenance	
Material	Selection	Defect or flaw	Variation within specification	Variation outside of specification	Processing history	Service history	Residual stress
Manufacture	Quality compliance	Method change	Supplier change	Variability	Poor specification	Processing history	Inappropriate method selection

Failure Causes							
Unexpected Service Conditions	Loading	Temperature	Pressure	Dynamics	Electromagnetic	Corrosive	Abrasive
Wear and tear / lack of maintenance	Fatigue	Corrosion	Contamination	Repair vs OEM standards	Maintenance schedule definition	Maintenance schedule adherence	Abrasion
Damage / abuse	Handling damage	Degradation during storage	Use outside of specification	Use for alternative purposes	Vandalism		

Failure Causes							
Fabrication / assembly	Standards - compliance	Standards - definition	Cleanliness	Fastener selection	Design for manufacture / assembly	Modifications / additions	

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