Chapter

Perspective Chapter: Smart Maintenance in Modern Ship Engineering, Design and Operations

Saulo Vasconcelos and Paulo Vasconcelos

Abstract

Marine Engineers are forged to face the most complex adversities of the maritime environment, whether in cabotage, maritime support, fluvial or on oil and gas rigs. Usually, the Marine Engineer is responsible for the production of potable water, lubricating oil and fuel system, sanitary and cooling system, propulsion system, electricity generation and others. This chapter will use quality tools, including the dart of Vasconcelos to quickly find the root cause of the problems. Troubleshooting is part of day-to-day job of an experienced Engineer, and he knows what kinds of techniques to use to troubleshoot and solve problems in an organized, quick and easy way.

Keywords: Marine Engineer, smart maintenance, troubleshooting, quality tools, dart of Vasconcelos

1. Introduction

The recent trend to design smart modern ships, more efficient with a high level of automation and processes control, this introduction of new technologies and changes in manning, requires from the Marine Engineers expertise to quickly solve the problems presented in the routine on board of modern merchant ships and oil rigs.

Marine Engineers are forged to face the most complex adversities of the maritime environment, whether in cabotage, maritime support, fluvial or on oil and gas rigs. Usually, the Marine Engineer is responsible for the production of potable water, lubricating oil and fuel system, sanitary and cooling system, propulsion system, electricity generation and others.

It is especially important to know the operating parameters of the systems and equipment, in order to give the correct diagnosis to his equipment and to know exactly which "medication" needs to be applied to solve the problem.

This chapter will use quality tools, the dart of Vasconcelos illustrated in **Figure 1** [1] to quickly find the root cause of the problems. Troubleshooting is part of day-to-day job of an experienced Engineer.

Figure 1.
Dart of Vasconcelos.

2. What is troubleshooting?

Troubleshooting can be defined as a logical search based on the symptomatic of a system or equipment, about what could be causing a particular problem, what would be its origin and how we could solve it to make the system or equipment operational again. One of the most important things to do an efficient troubleshooting is have a considerable knowledge from the subject in question, that can be obtained from the job experience and/or from a database (often from the system or equipment catalog itself) which provides a basis for the failure analysis that occurred.

Therefore, in summary, troubleshooting can be viewed as a careful way, which allows to accurately identify all the details of the system and, from that it is possible to make small changes in order to arrive at the root cause of the failure, as well as the to analyze each of the listed hypotheses to see if they can solve the problem effectively.

2.1 Dart of Vasconcelos

The basics steps of a good troubleshooting consist in identify the faced problem, establish a theory for the problem, test the theory, establish an action plan, and implement the solution. It is also possible to divide the troubleshooting sequence in define the problem through the ***Symptomatic***, do a ***Logical Search***, creating hypotheses, do the ***Contestation***, reducing the hypotheses and, finally, proceed with the ***Solution*** to solve the problem, where the hypotheses are tested and confirmed. Therefore, we can simplify that sequence through the of "Dart of Vasconcelos" illustrated in **Figure 1**.

Symptomatic:

Definition of the problem. It is essential to understand the system affected and what should be analyzed. It consists on the title of the troubleshooting.

Example:

1. Main engine #02 running with low fuel oil pressure. Title could be: "**Low fuel pressure oil on main engine #02**".

Logical Search:

Create hypotheses. Consist in analyze what systems or equipment are being affected by the problem and in to do the temporal analysis of the problem, the timeline, to be able to formulate hypotheses for the problem. In other words, create hypotheses to know exactly what should be inspected in each situation. Obviously, this will require good knowledge of the equipment and system in question, as well as the help of drawings, catalogs and manuals to understand the operation of what is being analyzed.

Example:

1. *System affected:* Fuel Injection System.

2. *Temporal analysis:* The problem occurred after maintenance on the fuel feed pump.

Creating Hypotheses:

1. Dirty or blocked fuel filters on engine.

2. Dirty or blocked strainer for fuel feed pump.

3. Fuel injector problems.

4. Bad fuel conditions.

5. Fuel feed pump wrong internal gear installed.

6. Fuel feed pump with clearance in internal gear.

Contestation:

Reduce hypotheses. At that phase, you should contest the hypotheses created with the intention of reduce at the maximum the possibility of causes for the problem. Discuss hypotheses with all involved on the troubleshooting task, making use of manuals, schematic drawings, maintenance history and other relevant information, until minimize the hypotheses.

To solve the problem, is essential eliminate hypotheses.

Reducing Hypotheses:

1. Dirty or blocked fuel filters on engine. Not possible, once engine was running with a good fuel pressure before to be stopped for pump maintenance.

2. Dirty or blocked strainer for fuel feed pump. Not possible due fuel pressure on suction and discharge lines of the pumps was good before pump maintenance.

3. Fuel injector problems. Not possible, Injectors were replaced recently, and no parameter indicated a injector problem when engine was running.

4. Bad fuel conditions. Not possible once other engine was running at that time and using the same fuel.

5. Fuel feed pump wrong internal gear installed. Possible, once can compromise the fuel flow and/or pressure.

6. Fuel feed pump with clearance in internal gear. Possible, once can compromise fuel flow and/or pressure.

Solution:

Solve the problem.

On that last step, once minimize the hypotheses, it is time to test each one, always starting from the easier one, to confirm and validate the hypotheses and finally find the solution for the problem. The correct diagnosis is extremely important. It is a critical part of the troubleshooting, once a wrong action can make you develop other undesirable problems and do the task harder, spending more time and producing emotional stress among the team and compromising the chance to quickly find the real problem. Remember to be organized and caution during the hands on for the tests.

Therefore, discovered the problem, the corrective action will be taken to put back on service the system/equipment. Remember to always log the problem with a report, thereby increasing the database to fix any such problems that may occur, and thus helping the team solve the problem in the future when you are not around.

Indeed, as the dart game has the intention to hit the bull's-eye, the Dart of Vasconcelos has the intention to hit it and solve the problem, which is the main target.

2.2 Practical example of troubleshooting

A particular ship began to show a significant loss of lubricating oil in one of its main electric power generation engines, after maintenance of replacing the liners and sealing rings of the corresponding pistons. In that case, the troubleshooting would lead us, assisted of the Dart of Vasconcelos, to reason as follows: (Definition of the problem: Symptomatic) what could be causing this significant loss of lubricating oil (Create hypotheses: Logical Search)? How to determine the source of the problem (Reduce hypotheses: Contestation) and how to act to make the system/equipment operational again (Solve the problem: Solution)? [1].

Symptomatic:

Significant loss of lubricating oil. Title: "**Loss of lubricating oil on engine**".

Logical search:

1. Lube oil purifier discharging excessive lubricating oil to sludge tank.

2. Lube oil leaking from pumps or hoses.

3. Lubricating oil passing through combustion chamber due seal ring damaged.

Contestation:

Reducing Hypotheses:

1. Lube oil purifier discharging excessive lubricating oil to sludge tank. Not possible, once was monitored the sludge tank level and tank level was according with expected.

2. Lube oil leaking from pumps or hoses. Not possible. Was inspected all engine for external leaking and nothing unusual was found.

3. Lubricating oil passing through combustion chamber due seal ring damaged. Possible, once the seal rings were replaced during maintenance. It could be allowing part of the lubricating oil to pass into the combustion chamber and be burned together with the engine fuel.

Solution:

Solve the problem:

To validate the possible hypothesis, is necessary to test to confirm. One way to identify with lube oil has been burned together fuel is to observe the color of the exhaust gases from the engine. If it is bluish gray in color, this means that the lubricating oil is probably being burned together with the fuel.

Another easy test to do is a compression test performed on the cylinders that passed for the maintenance. The cylinder with low compression pressure should certainly be the cylinder with the problem.

Therefore, once done the correct diagnosis, proceed with the corrective action. Carry out the inspection on the cylinder with low compression pressure and confirm the damaged seal ring and then, replace it. Register the problem making a report, once it increases your database of troubleshooting for any similar problems that may happen and assist the team to solve problems when you are not around.

2.3 Ishikawa diagram/fishbone diagram

The Ishikawa diagram, or Fishbone diagram, as it is also known, is a cause-and-effect diagram that helps to find the root causes of a problem, analyzing the factors that involve the execution of the process. This method was created by the Japanese Kaoru Ishikawa in the 60's and it's highly used today in the most diverse industries. The main factor of the diagram is to consider all aspects that may have generated the problem, thus making it easier to organize ideas to arrive at a solution for the problem.

It is a fact that every problem has specific causes. Analyzing each cause and verifying the possibility that it is the root of the problem is the key to finding a solution. It is necessary, whenever possible, to analyze the simplest and most probable causes of the problem, in order to save time and avoid hard and exhausting work during troubleshooting.

The great relationship of the Ishikawa Diagram with the spine of a fish comes from the fact that we can consider the spines as the causes of the observed problems, which will contribute to the discovery of their effect. The Ishikawa Diagram has great applicability in different contexts and in different ways, among them, the use stands out:

1. To view the main and secondary causes of a problem (effect).

2. To broaden the vision of the possible causes of a problem, seeing it in a more systemic and comprehensive way.

3. To identify solutions, raising the resources available by the company.

4. To generate process improvements.

2.4 How to make an Ishikawa diagram?

In order to carry out the Fishbone diagram, we must take the following steps:

1. Define the problem causes (effect) to be analyzed.

2. Draw a horizontal arrow pointing to the right and write the problem inside a rectangle located at the tip of the arrow.

3. Brainstorm to raise possible causes that may be causing the problem. To do this, try to answer the following question: "Why is this happening".

4. Divide the causes identified into categories, for example: machine, manpower, method, mother-nature, measure and materials or in a way that is most consistent with the problem analyzed and the context of your company.

5. Right after, define the sub-causes, that is, the factors that caused that cause to happen.

The main categories represented in each of the spines are also known as the "6 M", referring to the following items:

1. Manpower (People): involved in the process.

2. Method: The way the process is performed. What are the procedures used, rules and requirements.

3. Machine: The equipment involved in the process.

4. Measurement: Analyze the metrics used. Analyze all the data generated from the process looking for failures.

5. Material: Evaluate all material used in the process, parts, for example.

6. Mother-Nature (Environment): Analyze the conditions of the place where the process is developed.

2.5 Benefits of using the Ishikawa diagram

It is easy to understand that the use of the diagram facilitates the visualization of the causes of problems and the effects caused by them. In addition, we cite as other benefits:

1. Facilitate team brainstorming, in order to facilitate the organization of ideas.

2. It helps to keep the focus of the whole team.

3. Show all possible causes at once, in an organized and segmented way.

4. It stimulates the solution of problems.

2.6 Example how to use Ishikawa diagram

As an example of how to use the Ishikawa diagram, let us see how it would be applied to identify high coolant consumption in an Engine Room in engines plant. As explained before, first you need to do the sketch of the fishbone diagram, writing the "6Ms" (cause) to find out the problem (effect). Once done that, each one of the "6Ms" should be analyzed in separate, showing what could be caused the high coolant consumption in the engines plant. It assists the brainstorm and make easier to find out the real cause of the problem. **Figure 2** shows exactly the diagram for the explained situation.

Therefore, as seen, the diagram facilities the visualization of what could be causing the problem. The next step would be to analyze among all the election causes, what would be the correct one to the problem, for after that, check how to solve it.

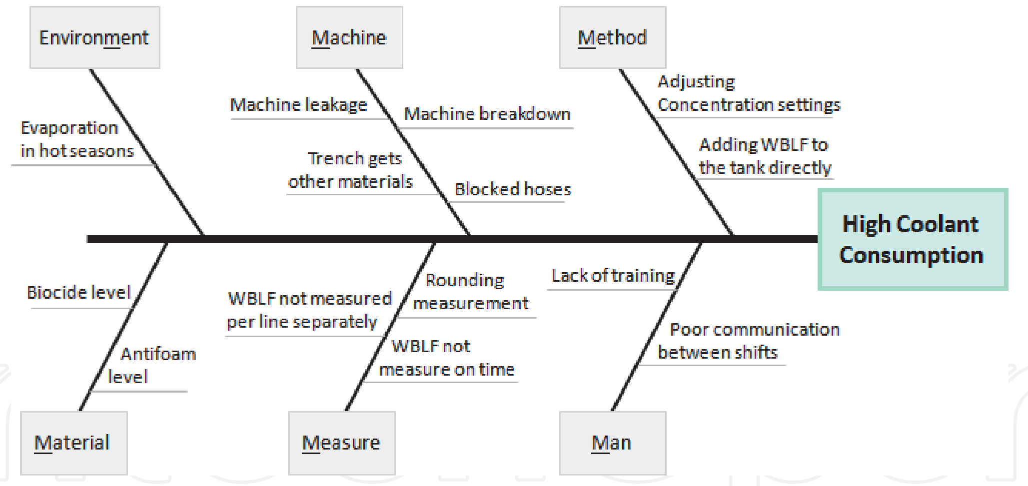

Figure 2.
Example of Ishikawa diagram. Causes that increased the coolant consumption in a manufacturing plant [1].

2.7 Difference between dart of Vasconcelos and Ishikawa diagram

Before all, it's particularly important to say that both methods are good and can be used for any problem of cause and effect. Ishikawa diagram use a wider view of the situation, while Dart of Vasconcelos is more objective, making faster to figure out what is causing the problem. Ishikawa is a type of diagram that anyone can participate, independent of being a maintenance team member, for example, a painter can say his opinion about one problem with his vision, making sense or not. The Dart, on the other hand, suggests that only people with affinity in the task raise opinions, so it becomes more objective and practical. Other difference is that Ishikawa shows the causes that could be causing the problem; the dart of Vasconcelos shows the causes and a way to solve them. Somehow, the person performing the troubleshooting can analyze which one method should be better applied for the present problem. To a better understanding, let analyze one situation using both methods.

2.8 Proposed problem

A specific diesel engine has been presented difficulty to start recently. Douglas, 2nd Marine Engineer, reported that this engine is with maintenance late and that has been presented an unusual and thick smoke from the exhaust gases. Therefore, could you find out the possible problem of the engine?

To proceed with that troubleshooting, let start using Ishikawa diagram and after the Dart of Vasconcelos. Therefore, building the fishbone for the problem, we have the following schematic illustrated in **Figure 3**.

Observe that the diagram has several causes for the problem (effect) and each one should be analyzed to confirm if it is a possible cause or not. At same time that diagram facilities the visualization of the causes, depending on the problem it can have many causes and sub-causes, becoming hard and lingering the task, once it seeks to look at the problem as a whole, and not objectively, based on the affected system and the on temporal analysis. Therefore, let us analyzing each cause:

1. Polluted or rarefied ambient air. Not possible. Ambient inspected and nothing unusual observed.

2. Incorrect parts used for maintenance. Not possible. Double checked part number to confirm parts used are correct.

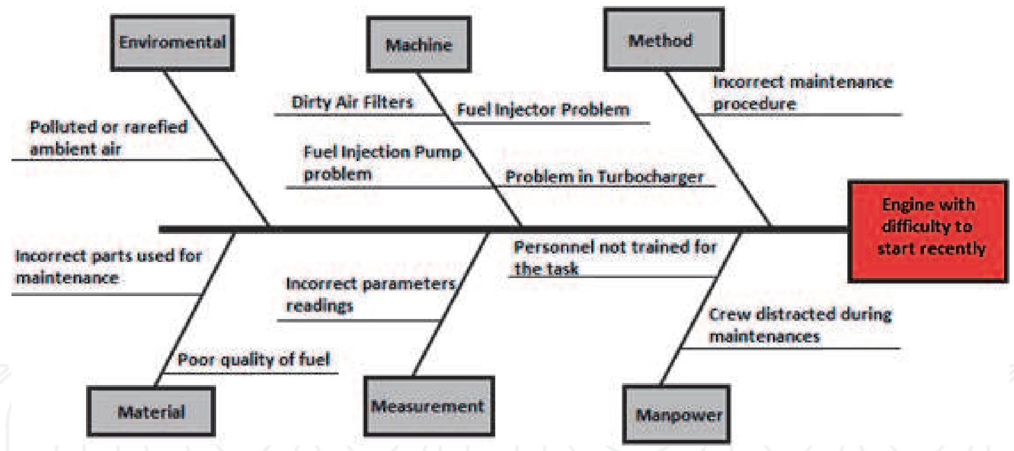

Figure 3.
Ishikawa's diagram for engine with difficulty to start recently [1].

3. Poor quality of fuel. Not possible. Collected a sample and saw that was in good conditions.

4. Air filters dirty. Possible.

5. Fuel injection pump problem. Possible.

6. Fuel injector problem. Possible.

7. Problem in Turbocharger. Possible.

8. Incorrect parameters readings. Not possible. Confirmed that instrumentation was working properly.

9. Personnel not trained for the task. Not possible. Experienced crew on the task.

10. Incorrect maintenance procedure. Not possible, Procedure used direct from the manufacture manual.

11. Crew distracted during maintenances. Possible.

Ishikawa diagram gives 5 possibilities for the problem. Analyzing each one we have:

1. **Dirty air filters**. Possible. An unusual and thick smoke from the exhaust gases reported by Engineer is a hint, once it indicates an uncomplete burn into the combustion chambers. Once maintenance is later, should be good check if air filters are not dirty and causing an obstruction of air.

2. **Fuel injection pump problem**. Possible. It can reduce the fuel pressure that pass to the fuel injectors.

3. **Fuel injector problem**. Possible. Same as dirty air filter, thick smoke from the exhaust gases reported by Engineer is a hint, once it indicates an uncompleted burn into the combustion chambers. Once maintenance is later, should be good check injectors for dirty nozzles or damaged. It is easier several injectors get dirty and occur the problem reported them injection pumps.

4. **Problem in Turbocharger**. Possible. If the temperature or pressure of the air into the turbocharger outlet is not according to the operational parameter, it indicates a bad condition of turbocharger. Other occurrence would be clogged turbocharger air filter element or any unsuitable cause in the air supply.

5. **Crew distracted during maintenances**. Possible. Besides crew team follows the manufacture manual procedures, if during the maintenance the team was distracted, they can forget some steps or not adjust as required injection timing, for example, that would cause same problem of dirty air filters, an uncompleted burn into the combustion chambers.

Therefore, electing the priority to be inspected (based on possibility and facility) we have inspect air filters, double check for the steps done with the crew during maintenance, inspect fuel injectors, inspect turbochargers, and inspect fuel injection pumps.

Now let us analyze the same proposed problem above using Dart of Vasconcelos:

Symptomatic: "specific diesel engine has been presented difficulty to start recently".

Definition of the problem: Engine with difficulty to start.

Logical Search:

1. System affected: Fuel system and air system.

2. Temporal analysis: Engine is with maintenance late.

Creating Hypotheses:

Based on symptomatic and the logical search, is possible significantly reduce the quantity of hypotheses, for example, poor quality of fuel will not be considered as a cause, once only one "specific" engine presented the problem, if was a common problem, certainly fuel would be a great possibility. The same happen to polluted or rarefied ambient air, using temporal analysis, nothing make reference about changes on the work engine area to consider it as a cause. Note that using this method, is possible to be more specific and surgical on the troubleshooting, saving time with possibilities that really are important to find out the problem.

Indeed, the following hypotheses for the question are:

1. **Dirty air filters**. Possible. An unusual and thick smoke from the exhaust gases reported by Engineer is a hint, once it indicates an uncomplete burn into the combustion chambers. Once maintenance is later, should be good check if air filters are not dirty and causing an obstruction of air.

2. **Fuel injection pump problem**. Possible. It can reduce the fuel pressure that pass to the fuel injectors.

3. **Fuel injector problem**. Possible. Same as air filter dirty; thick smoke from the exhaust gases reported by Engineers is a hint, once it indicates an uncompleted burn into the combustion chambers. Once maintenance is later, should be good to check injectors for dirty nozzles or damaged. It is easier several injectors get dirty and the problem reported in injection pumps occurs.

4. **Problem in Turbocharger**. Possible. If the temperature or pressure of the air into the turbocharger outlet is not according to the operational parameter, it

indicates a bad condition of turbocharger. Other occurrence would be clogged turbocharger air filter element or any unsuitable cause in the air supply.

Contestation:
Reducing hypotheses.

1. **Fuel injection pump problem**. Unlikely. would be necessary more of them one injection pump problem to the fault reported. Not so common several fuel injections pumps with problem at the same time.

2. **Problem in Turbocharger**. Unlikely. Other several problems would occur if the turbocharger problem happened, and certainly a characteristic and uncomfortable noise would be noted. The Marine Engineer also not reported any high temperature alarm in the turbocharges or cylinders, that would be common for high temperature in the outlet of the turbocharger.

Solution:
Solve the problem.

Therefore, the possibilities of the problems were reduced in two, dirty air filters or injector problems. Starting from the easier to inspect and solve, inspect air filters for clogged and replace it. For fuel injector, inspect all injectors for carbonization on nozzle, test the pressure of opening and how the spray, and check for inappropriate injection timing is.

In summary, using both methods will be possible find the causes to finally solve the problem. Vasconcelos method shows more objectivity, and Ishikawa looks the problem as a whole. The person in charge doing the troubleshooting will decide which method will be better for each situation.

2.9 Availability and reliability of equipment and plant operation

MTBF (mean time between failures) and MTTR (mean time to repair) are two indicators related to the availability of an Industrial Process.

2.9.1 MTBF

These are the periods of time that are lost while the machine is running and can be averaged using a formula. We have to apply the total performance time during a predetermined cycle under the number of failure that occurred during such time. According the Formula: MTBF = (Total Available Time – Waiting Time) / (numbers of shutdowns in the period of operation).

Example a freshwater generator designed to operate for 24 hours per day. Suppose the freshwater generator shutdown three times in the span of 30 days. The first shutdown occurred 48 hours from the start time and took 6 hours to repair. The second shutdown occurred 240 hours from the start time and took 4 hours to repair and the last shutdown 480 hours from start time and took 2 hour to repair before the freshwater generator was operating normally.

MTBF = (30daysx24hours - (6 hours + 4 hours+2 hour))/(3 shutdowns in 30 days of operations time) = 714 hours/3 = 236 hours or a mean time of 9 days and 20 hours between failures in the span of 30 days of the freshwater generator operation time.

With this conclusion, strategies can be created to face a problem gradually associated with the equipment.

2.9.2 MTTR

MTTR is calculated by applying the average time it takes to perform a repair after the failure episode. See the formula: MTTR = (Total repair time) / (number of failures). If you use the example above, you should get the following solution:

MTTR = (6 + 4 + 2) / 3 = 4 hours.

This solution establishes the average time that the equipment was stopped. Generating a relationship with the two indexes is the availability of this process.

AVAILABILITY = MTBF/(MTBF+ MTTR).

Therefore the availability of the freshwater generator in this process on board of a vessel is:

AVAILABILITY = 236 hours/(236 hours + 4 hours) = (236/240)x100 = 98,34%.

Thus, the lower the MTTR and the higher the MTBF, the more efficient the maintenance team will work.

Reliability of an equipment is related with the MTTF (mean time to failure), or failure rate, which expresses the probability of the equipment failures during a given period of time. It's normally applied to unrepairable devices, such as electronic devices and some relays with expected life of 300,000 cycles of operation or more or less 10 years of span life.

3. Troubleshooting based in real cases

In this part, is showed the questions based in real cases. Some of questions, before to be presented, have an initial introduction about the subject debated into the question, in order to help the reader to solve the problem. The reader may use one of the cause and effect methods spoken in the beginning of this chapter and use the ***hints*** of the questions for assistance him. Feel free to decide which one is better for you. Therefore, with no more conversation, let us initiate the troubleshooting!

3.1 Generator: Excitation

A specific, Dynamic Position vessel class #02, with electric diesel engines, configured with two medium voltage busbars, a bus tie breaker, four brushless diesel generators, two fixed pitch propellers and four tunnel thrusters illustrated in **Figure 4** [1].

Laura, an experienced Marine Engineer was ordered to prepare the engines, once the operations have finished at that port, so the vessel had to leave. The Diesel Generator 01 was on the busbar, with the bus tie breaker closed, as shown in **Figure 5**.

Therefore, Laura activated the Power Management System (PMS), so that the others diesel generators feed the busbars, thus making four generators on the busbars, to then drive the propulsion's loads. However, the engineer was surprised,

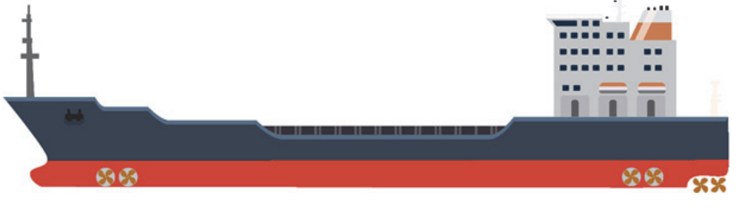

Figure 4.
Electric diesel vessel with 2 fixed thrusters and 4 tunnel thrusters [1].

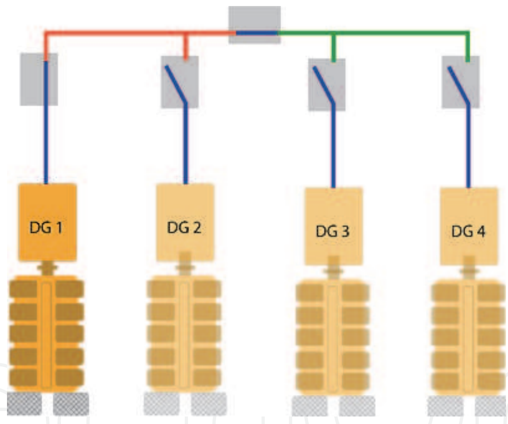

Figure 5.
Screen from power management system (PMS) during vessel operation at the port [1].

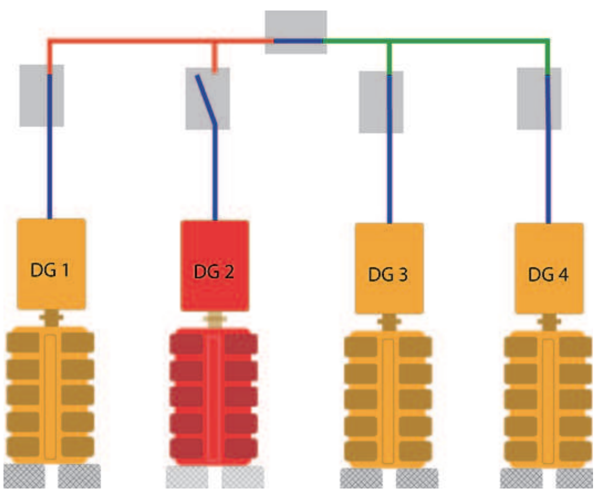

Figure 6.
Condition of screen from power management system (PMS) during the failure alarm [1].

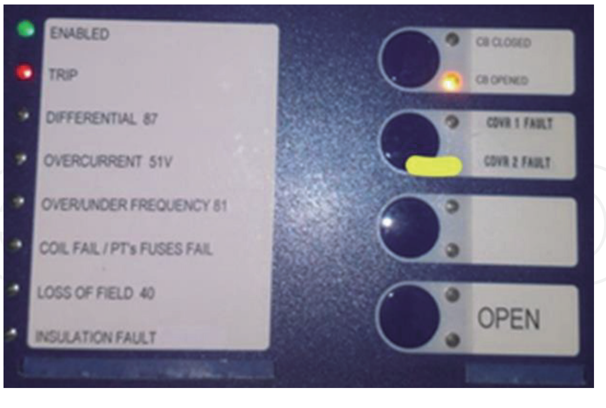

Figure 7.
Protection relay SEL – 7000G [1].

as generator #02 did not assume the load, generating several alarms, among them Automatic Voltage Regulator (AVR) fault, in the protection relay of generator #02, illustrated in **Figures 6** and 7.

Observing on the Bridge, **Figure 8**, the Captain called to Engine Room to understand why the generator had not assumed the load, once the company's procedure require that all generators should be on the busbars for the vessel to leave the port until navigation. Laura replied that she was investigating, doing her troubleshooting while, the Chief Engineer and the electrician were on their way to

Figure 8.
AVR switch button [1].

inspect the problem. Marine Engineer knew that this DP class #02 vessel had a lot of redundancy until arrives at the generator #02 busbars control cubicle, she recalled that each diesel generator had two AVRs, and then she quickly deselected the AVR #01 and selected the AVR #02, resetting the SEL 7000 bus protection relay.

At this moment, the Chief Engineer arrived at the Machinery Control Center (MCC) and Laura reported what she had done, promptly the Chief praised her and signaled her to continue the procedure that was underway with the electrician. Together, after all the conferences and resets, Laura, and the electrician Jair, issued the order for the PMS to start generator #02, which excited, synchronized, closed the circuit breaker on the busbars, and divided the load normally. Chief Engineer Nikola Tesla, asked to electrician Jair to look for a new AVR in the electric Warehouse, to replace the AVR #01, even so, Nikola thought about doing some tests.

Therefore, he requested that the Captain activate the tunnel thrusters above the port in two ways:

1. Slowly activating the thrusters with only generator #02 on the busbars.

2. Quickly triggering thrusters with generators #01 and # 02 on the portside busbars, illustrated in **Figure 9**.

Vessel responded well, there were no alarms, or the opening of the generator #02 circuit breaker on the busbars.

Thus, this vessel definitively left the port for navigation towards its offshore operations and the Chief returned to rest as well as the electrician, after troubleshooting, to then follow the next operations.

Gabriel, the First Engineer, assume his duty service, and after his normal round, started a revision service for a fuel oil purifier that Laura had started on her shift,

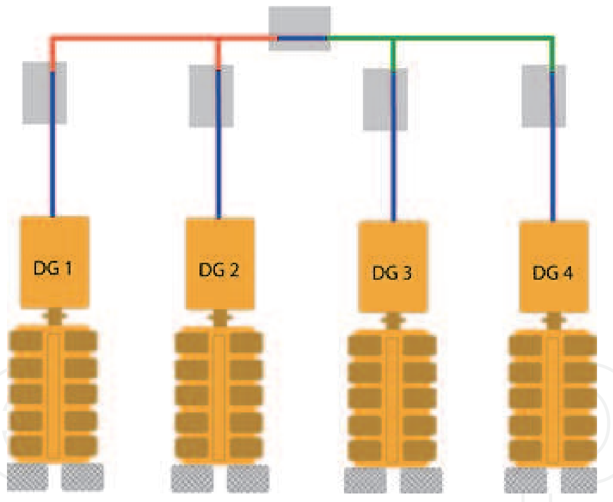

Figure 9.
Condition of main busbars during navigation to offshore operations [1].

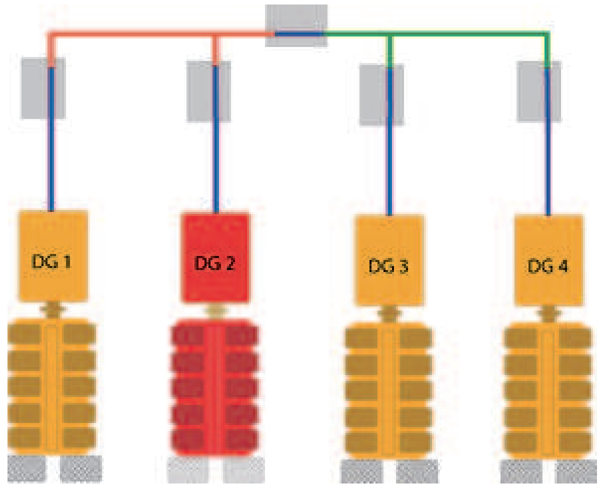

Figure 10.
Condition of main busbars during navigation after generator failure [1].

once the ship was navigating, and there would be enough time to finish that maintenance service.

As soon as the maintenance started, Gabriel observed a change in the charge regime of generator #02 due to the sound emitted by it, and soon there was an alarm. The engineer went to the MCC, noting the condition of generator on PMS screen, seeing that the Generator had disconnected from the busbars with a series of alarms, among them: "AVR Fault", again as illustrated in **Figure 10**.

At this moment, the electrician Jair said: "we need to see this, can be a serious problem!", because he knew that Laura had selected another AVR during troubleshooting, on the night before, and it would be very unlikely that both AVRs had failed.

Time was running out before the vessel reached the platform, so Gabriel decided to communicate Nikola, because only with three generators, there would be a reduction in contract speed, compromising the contract speed with the client. Since the vessel was equipped with PMS there was no blackout, the thrusters were automatically reduced and until then the Deck officers had not noticed any difference in the speed of navigation. So, when Chief Nikola arrives at MCC, Jair and Gabriel were already exchanging the AVR that Jair had already brought from the electric Warehouse. Nikola, very dissatisfied just observed what Gabriel and Jair were doing. Nikola is an experienced Chief Engineer and knew that the chance of two

AVRs failing together would be very low. Therefore, Nikola looked for the excitation / load control diagram of generator #02, while Jair and Gabriel were replacing the AVR. Nikola knew the order of events in which a generator needs to synchronize in parallel with another generator:

1. Order to depart the generator that must happen in a certain time.

2. Exciting (or increasing the AVR tension value), that should happen in a certain time.

3. When achieving the tension value of the busbars, which cause small rotation slips until the generators and the busbars have the same phase angle that must to happen in a certain time.

4. When achieving the same phase angle displayed in the synchronoscope which must be an order to close the circuit breaker.

5. There are number of attempts to close the circuit breaker. If the circuit breaker does not close, there is an engine stop order.

When the breaker closes, the loading generator increases the AVR current injection as well as fuel injection in the diesel machine while the generators that are giving load do the reverse process.

Telemetry Mesh called "loading sharing" communicates data to ensure that the Kilo Watts (KW) load values in both generators are equal, maintaining the AVR control process / fuel injection according to the electric load charges of the busbars.

Before Chief Nikola continued his analysis, Jair and Gabriel notified the order of the change in the AVR. Not ensured about the change done, they started the test. Generator #02 curiously connected on the busbars normally. Jair and Gabriel, were incredibly happy, shook hands and praised each other. Nikola thanked, but still dissatisfied said: Let us test!

Thus, at this moment, Chief Mate Fernanda, who had already been notified, started to take charge in several ways, thrusters against each other, all forward and all reverse and still generator #02 remained on the busbars. Jair and Gabriel were certain that everything was right, after all, in these tests, generator #02 remained on the busbars, the tests were severe, if anything that had to happen would happen during the tests. When Jair went to boast to the Chief, Nikola, who was focused on reading the electrical diagram, said to him: I am going up, call me when this generator leaves the busbars again! Skeptical and upset Gabriel said: Chief, it is settled, we have done the tests! Nikola replied with a friendly smile: Dear friend, thank you for your effort, your work was excellent, but call me again when this generator is disconnected from the busbars. Nikola turned his back and left MCC.

Gabriel told to Jair that the Chief was very suspicious fellow. Jair said that Nikola thinks him is the master of all the machines, he thinks that he invented the generator! After all, the electrician was Jair. Gabriel already calmer, said: Jair, you know how it is, right? Chief is Chief.

Thus, Jair said goodbye to Gabriel and went to change some lamps of the vessel, and Gabriel went to continue the service in the Purifier of diesel oil.

Time passed, the purifier was set up, Gabriel called Danilo, Oiler, to clean the environment of the purifier, when again generator #02, presented unusual noise and failed!

Surprised and incredulous, Gabriel said: what a Chief! Going up to the MCC where the generator #02 cubicle was located, he found the Chief with a Laser

Temperature Gun (LTG) in his hand, measuring temperature inside the generator #02 cubicle. Nikola called Jair and said, change this component, giving Jair an electric contactor, and pointing out on the board which one he wanted to be changed. Jair, feeling pressured by the constant defects, changed the component requested by Chief Nikola. Even when driving in different ways, thrusters against each other, all the power in front and all the power in reverse, generator #02 remained on the busbars. Nikola said: Now the problem is solved!

Therefore, could explain what was the Chief Nikola Tesla thinking and how he found out that the electric contactor was the real problem?

Hints: Field and excitation coils.

Solution:

To understand and solve this problem, is important observe the timeline analysis of the problem. Three AVRs failed. First AVR failure with Laura, it was replaced by it hot stand by AVR # 02 in 1 hour by Laura, and then failed again after 6 hours and was replaced by a new one in 1.5 hour of service, lastly, other AVR failed after 4 hours with Jair and Gabriel and again was replaced for a new one in 1.5 hour of service. The same failure happens with all AVRs, what easily suggest that the problem may not be this component and yes, another item common to for the AVRs. The purpose of an AVR, illustrated in **Figure 11** is to control the voltage of a generator by injecting current into the exciting coil. When you turn on a heater in your cabin, for example, the current in the generator armature increases and the magnetic field crossing the armature decreases due Lenz law, so the output voltage drops. To prevent this to occur, the AVR increases the current injection in the main exciter, increasing the magnetic field of the coil, consequently the field crossing the armature, and finally the output voltage to it set point.

When someone turns on a lamp, the AVR injects more current into the main exciter, when someone turns off, the AVR decreases the excitation, so the set point remains constant. If this control were manual, you would be in front of the electrical energy board all day increasing or decreasing the field excitation value manually. But what is it to do with this contactor?

The contactor switches the AVR, without power the AVR does not works, if this contactor fails, the AVR fails. On the Other hands, if so, the generator would not work under any conditions, even when the AVRs were changed, much less in the tests performed, and every time the generator was switched on, it would fail, as it would not reach the excitation voltage. However, this was an intermittent failure. Observe the Direct Chain (DC) voltage coil illustrated in **Figure 12**.

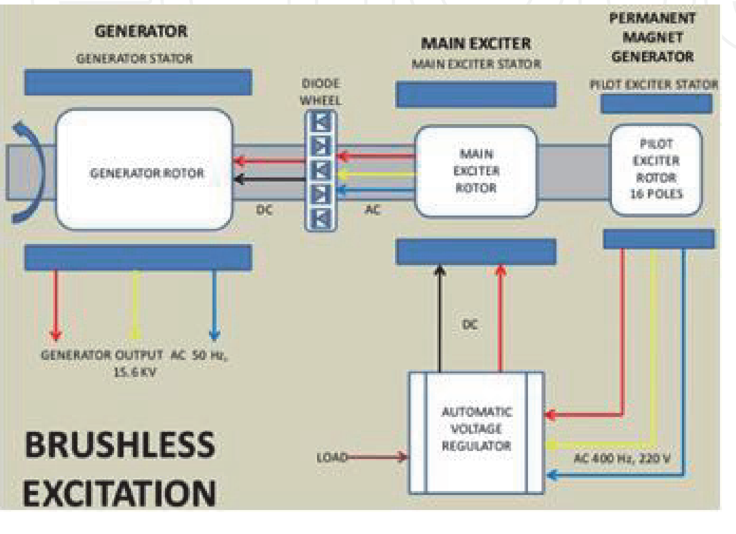

Figure 11.
Excitation system for a brushless alternator [1].

DOI: http://dx.doi.org/10.5772/intechopen.99027

Figure 12.
DC voltage CWM coil [1].

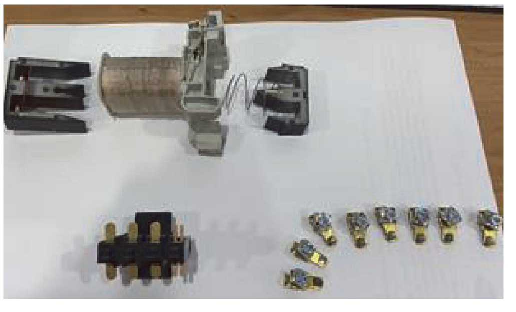

Figure 13.
Disassembled CWM DC contactor [1].

This coil works with a small voltage value, so it must be relatively large to keep the contactor's contacts closed, it must have many turns to have a great magnetomotive force at a little current, so the wire gauge is small. The vessel was more than 10 years and probably that coil was never changed, suffering years of heating on it made the varnish of the wire that constitutes the coil lose its insulation, even more when in use, this short-circuits insulation, causing the coil to lose some turns, decreasing the magnetomotive force. During some heating, the coil loses strength, the ship vibrates, this generates an instant lapse by opening the contacts and closing again, which switches off the AVR, so the generator stays momentarily without voltage control, so there will be no way to work in parallel with another engine. Therefore, it was what happened. **Figure 13** shows the damaged contactor disassembled.

Note that the contacts are in bad conditions. When Chief Engineer was checking the temperature inside of electrical board, he observed the contactor (common for both AVRs) heater than the others. Usually, the number of operations wears the contacts and thus, the contactor has some defect, bad terminals, or something, but it was measured an increase in the temperature of the coil and not in the contacts. in a DC coil, the current is limited by the ohmic resistance of the wire, so it needs a lot of turns, to produce a strong magnetomotive force to close tightly the contacts So, it was a real guess, because it's known that coils are sensitive to temperature, after all the temperature degrades the varnish isolation.

When was disassembled another contactor of a new model, it was possible to compare and ratify the Chief Engineer theory, as illustrated in **Figure 14**.

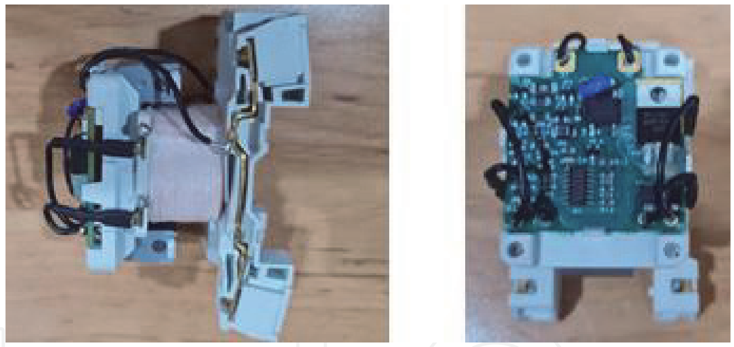

Figure 14.
Disassembled new contactor model [1].

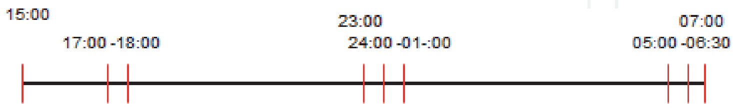

Figure 15.
Timeline for the failures in the generator # 02 synchronization in the busbars.

Notice that the coil of the new models is smaller and has an electronic card, the 24 VDC supply feeds the card which energizes the coil, the card generates an alternating current (AC) wave, which feeds the coil. So, who starts to limit the current value is the impedance of the coil, the number of turns of the coil decreases due to the inductance, so the length of the coil decreases, the ohmic resistance of the wire decreases, thus, the heating decreases, less resistance, less active power dissipated in the form of heat, less heat, greater longevity for the coil lifespan.

Indeed, a simple electric contactor was causing those all problems and compromising the safety navigation of the ship. A better analysis and a correct diagnosis are especially important; otherwise you can create even bigger problems.

3.2 Availability and reliability of generator # 02

Mariners Engineers work in shifts of 08 hours as can be seen in **Figure 15**, showing the timeline of this failure of generator # 02.

MTBF for the failures in generator # 02 in the period of 2 shifts of 08 hours:

MTBF = (2 shiftsx08hours - (1 hours+1.5 hours +1.5 hours))/(3 shutdowns in 16 hours) = (16–4) hours/3 shutdowns = 12/3 = 4 hours.

MTTR is calculated by applying the average time it takes to perform a repair after the failure episode.

MTTR = (Total repair time) / (number of failures). According **Figure 15** we have:

MTTR = (1 + 1.5 + 1.5) / 3 = 4/3 = 1.33 hours.

AVAILABILITY = MTBF/(MTBF+ MTTR).

Therefore the availability of the generator # 02 in 2 shifts is:

AVAILABILITY = 4 hours/(4 hours+1.33 hours) = (4/5.33)x100 = 75%.

The reliability (MTTF) for the DC relay, is considered as for unrepairable devices, in this case it is hope the lifespan of 10 years for this relay, so its failure is consider due to lifespan.

The new relay with AC coil it is expect a longer lifespan than for the DC coil relay due to lesser Joule loss in the AC coil, and Chief Tesla will implement a predictive maintenance plan, measuring the temperature in the electric cubicle in every six month.

4. Conclusion

The objective of this chapter is to contribute with readers responsible for the maintenance of vessels, petro rigs and any industrial processes control plant.

Focused on a smart way for rapidly to solve routine problems on board faced by Marine Engineers, it was prepared a revision in the literature concerning trouble-shooting, describing how to prepare and use the Ishikawa diagram and also compare with the dart of Vasconcelos developed by Saulo Vasconcelos. In this real case study the Chief Engineer applied the dart of Vasconcelos to reduce the MTTR and shows the solution for the electric problem of the electric generation # 02, caused by an electric contactor that switches the AVR (Automatic Voltage Regulator), The Mar-iners Engineers, without troubleshooting the problem replaced three times the AVRs without success to find the root cause of the problem. The Chief Nicola Tesla, applying the dart of Vasconcelos, reached the bull's eye of the problem, the old DC electric contactor. The dart of Vasconcelos directs for root cause and also to avoid future problem, recording the timeline of the problems until the final action, in this real case study the installation of new electric contactor with AC coil with longer lifespan for its AC coil, increasing availability and reliability of the Diesel-electric system of this ship.

Acknowledgements

The authors would like to thanks the LORD GOD for this opportunity, the Admiral Braz de Aguiar Maritime Academy for the authorization to public this work, and to inTechOpen Access Publisher for the virtuous circle created to share knowledge between readers and authors.

Author details

Saulo Vasconcelos and Paulo Vasconcelos*
Admiral Braz de Aguiar Maritime Academy, Belem, Brazil

*Address all correspondence to: douglasic@uol.com.br

Reference

[1] Vasconcelos D, Saulo. Troubleshooting for Marine Engineers with Real Cases. Marine Insight Publisher; 2021. ISBN: 978-65-00-22161-9