ROOT CAUSE FAILURE ANALYSIS OF A GAS TURBINE STARTER FAILURE

By

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD ABU BAKAR BIN MOHD ALI

ABSTRACT

The purpose of a starter is to produce a high torque and transmit that torque to the engine rotating assembly in a manner that provides smooth acceleration from rest up to a speed at which the gas flow through the engine provides sufficient power for the engine turbine to take over. Starter failure proves to be quite costly in terms of cost, time and company production itself, as it purpose itself are to, in simple words, start the gas turbine The objective of this project is to study the failure analysis of a gas turbine starter during start up and provide corrective action to prevent the recurrence of the incident.

Normally in the industry, FRACAS (Failure Reporting, Analysis and Corrective System), are widely applied. This system promotes reliability improvement throughout the life cycle of the equipment. In this research, the main cause of the starter failure during start up is investigated under an existing case in the industry. Basic failure analysis tools, as for in this case, the fault tree analysis was carried out in order to point out the possible causes of this incident.

The incident initially detected as lube oil burst out from the exhaust line during startup, startup was immediately aborted and starter was sent for inspection. Background history shows no anomalies in the starter condition, however, in the system condition, some anomalies were detected in the DCS reading during startup. Starter inlet pressure during start peaked at 11.50 BarG which was well above the specified maximum operating inlet pressure for the starter. During tear down inspection, components in the turbine section of the starter were severely damaged. With the failed item obtained, a root cause analysis was carried out and it pin points that the pressure control instruments (PY-1192 through XV-1192 setting) may have failed to control the inlet pressure to the starter. Recalibration of XV-1192 was carried out immediately and the next startup after calibration shows normal starter inlet pressure as it peaks at 7.27 BarG. Therefore, the main cause of the starter failure is due to excess pressure which results from XV-1192 valve setting, which is troubleshooted by recalibration of XV-1192 valve setting.

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The author is grateful to the Maintenance Rotating Department, Gas Processing Plant B, under Petronas Gas Berhad (PGB), for the support and facilities provided to carry out the experimental work. The author is also grateful to the staff of PGB's laboratory for their support, assistance and friendly treatment that not only facilitated the work, but also made it pleasant.

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Chapter 1

Introduction

1.1 Background Study

The purpose of a starter is to produce a high torque and transmit that torque to the engine rotating assembly in a manner that provides smooth acceleration from rest up to a speed at which the gas flow through the engine provides sufficient power for the engine turbine to take over [3]. Starter failure proves to be quite costly in terms of cost, time and company production itself, as it purpose itself are to, in simple words, start the gas turbine[1].

Failure in this case may occur due to various factors that may multiply the damaged inflicted. Thus, normally in the industry, FRACAS (Failure Reporting, Analysis and Corrective System), are widely applied [4]. This system promotes reliability improvement throughout the life cycle of the equipment. The method can be used during in-house (laboratory) tests, field tests, and production / operations to determine where problems are concentrated within the design of the equipment.

In this research, the main cause of the starter failure during start up will be investigated under an existing case in the industry. Specific parameters will be observed, during start up, and contrasted, if some abnormalities are detected, among the gas turbine units on the plant. Basic failure analysis tools, as for in this case, the fault tree analysis will be carried out in order to point out the possible causes of this incident.

1.2 Problem Statement

1.2.1 Problem Identification

The problem developed while starting up a land gas turbine on the plant. A loud noise and sudden burst of lube oil from the starter discharge vent were observed during engine ignition. Immediately, the air supply to the starter was stopped and the engine was shut down. The pneumatic starter was found broken and oil was leaking from the turbine section. Subsequently, the starter was sent back to the manufacturer as the same case happens twice in a row at the same unit of gas turbine.

1.2.2 Significant of the project

The inspection and analysis that will be done in this project is significant to know the main cause behind the failure of the starter during start up. Other than the starter condition itself, it is essential to know the other external variables such as the control system performance. By this, the main reason can be identified thus preventing the failure form occurring again on the turbine unit.

1.3 Objective

The objective of this project is to study the failure analysis of a gas turbine starter during start up and provide corrective action to prevent the recurrence of the incident.

1.4 Scope of Study

The scope of work of this project is to study the failure analysis of a gas turbine starter during start up and provide corrective action to prevent the recurrence of the incident. Equipment history within a selected time frame will be evaluated and root cause analysis will be carried out corresponding to the data evaluated. Corrective action will be selected in order to prevent the recurrence of the incident.

1.5 The Relevancy of the project.

Pneumatic starters of gas turbines are widely used in the oil and gas industry in Malaysia, most prominently in a gas and chemical processing plant. Failure without warning occurred almost all the time which could disrupt the plant production as also it was proven to be costly. This project should be able to minimize those risks by identifying and troubleshooting the main problem in the unit and the system.

1.6 Feasibility of the project

It is required for all the Final Year Students to complete their project within two semesters of study. Therefore, proper planning has been developed at the beginning of the project to make sure that the project can be completed and the objective of the project can be achieved within the time frame.

Chapter 2

Theory and Literature Review

2.1 Gas Turbine Engine

2.1.1 Theory of Operation

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between.

Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas.

Gasses passing through an ideal gas turbine undergo three thermodynamic processes. These are isentropic compression, isobaric (constant pressure) combustion and isentropic expansion. Together these make up the Brayton cycle[7], as shown in Figure 1 .

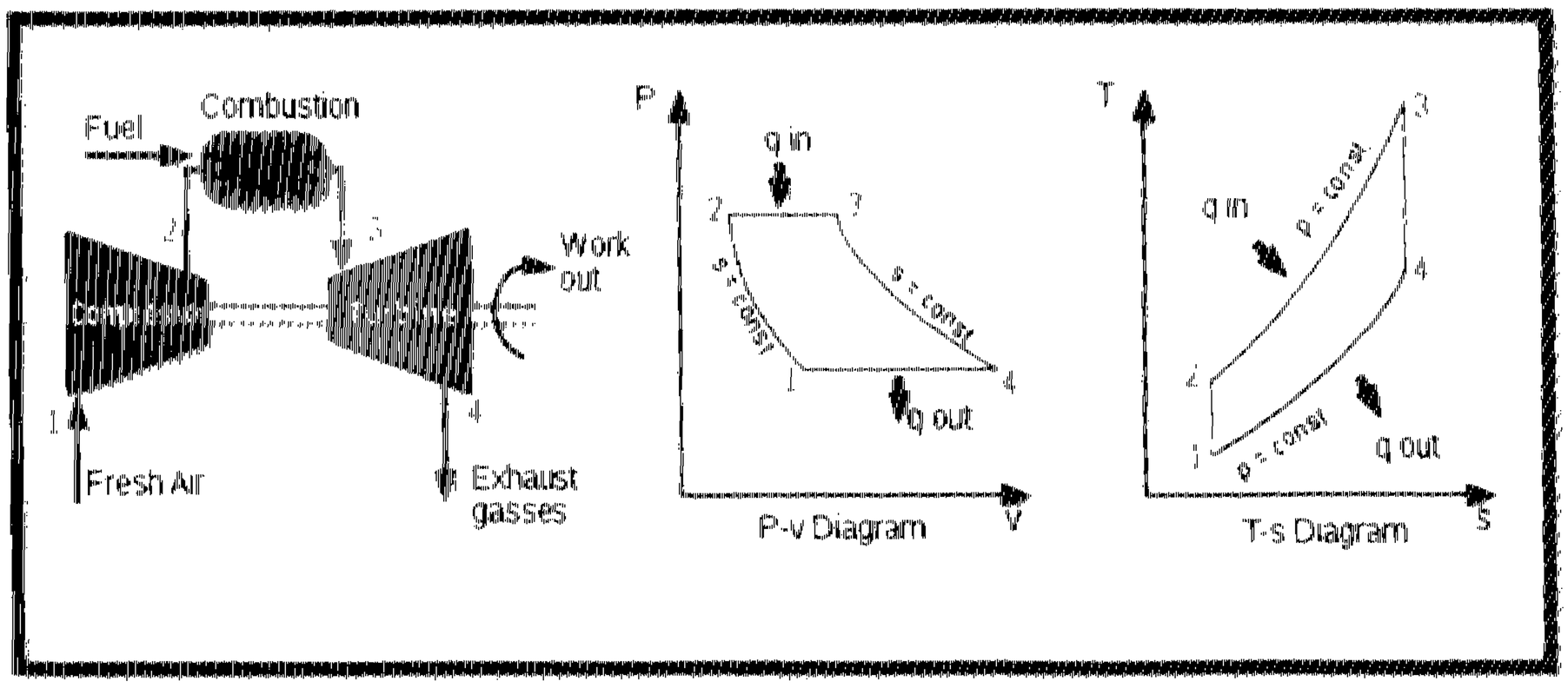


Figure 1: Brayton Cycle [7].

In a practical gas turbine, gasses are first accelerated in either a centrifugal or radial compressor. These gasses are then slowed using a diverging nozzle known as a diffuser; these processes increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gasses then pass from the diffuser to acombustion chamber, or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition). As there is no change in pressure the specific volume of the gasses increases.

Finally, this larger volume of gasses is expanded and accelerated by nozzle guide vanes before energy is extracted by a turbine. In an ideal system these are gasses expanded isentropically and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence.

2.1.2 Gas Engine Specification

The gas engine specification for this project is shown in table 1:

Table 1: Basic Specifications of GE LM 2500[10].

Model	GE LM 2500
Output	25,060 kW
Heat rate	kJ/kWs-hr
Exhaust gas flow	70.5 kg/sec
Exhaust gas temperature	566°C
Power Turbine Speed	3600 RPM
Thermal Efficiency	36%

2.2 Pneumatic Starter

The pneumatic starter, air starter or sometimes called the air turbine starter, is the most common in use today. The starter includes a turbine with a preceding nozzle guide vane (NGV) stage, a reduction gear and a clutch.

2.2.1 Theory of Operation

An air starter motor has a turbine rotor that transmits power through a reduction gear and clutch to the starter output shaft that is connected to the engine. The starter turbine is rotated by air pressure taken from an external ground supply. The air supply to the starter is controlled by an electrically operated control and uses a pressure reducing valve that is opened when an engine start is selected. This valve automatically closes at a predetermined starter speed. The clutch also automatically disengages as the engine accelerates up to idling RPM and the rotation of the starter ceases. The component section is shown in Figure 2.

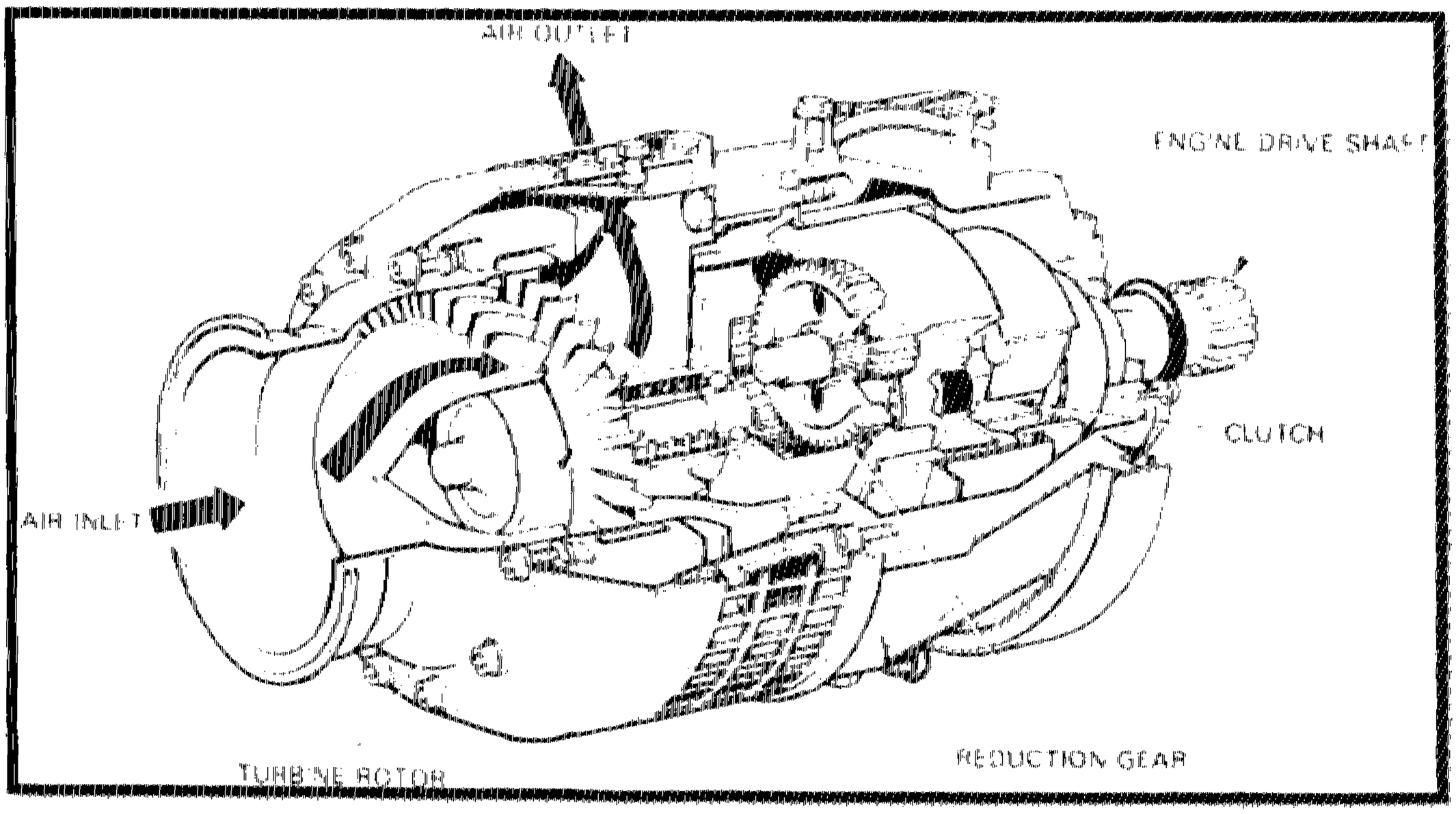


Figure 2: Pneumatic starter [3].

2.2.2 Starter specifications

Starter that was used in this study was a pneumatic starter developed by TDI Tech Development. The standard configuration of the starter is shown in Figure 3.

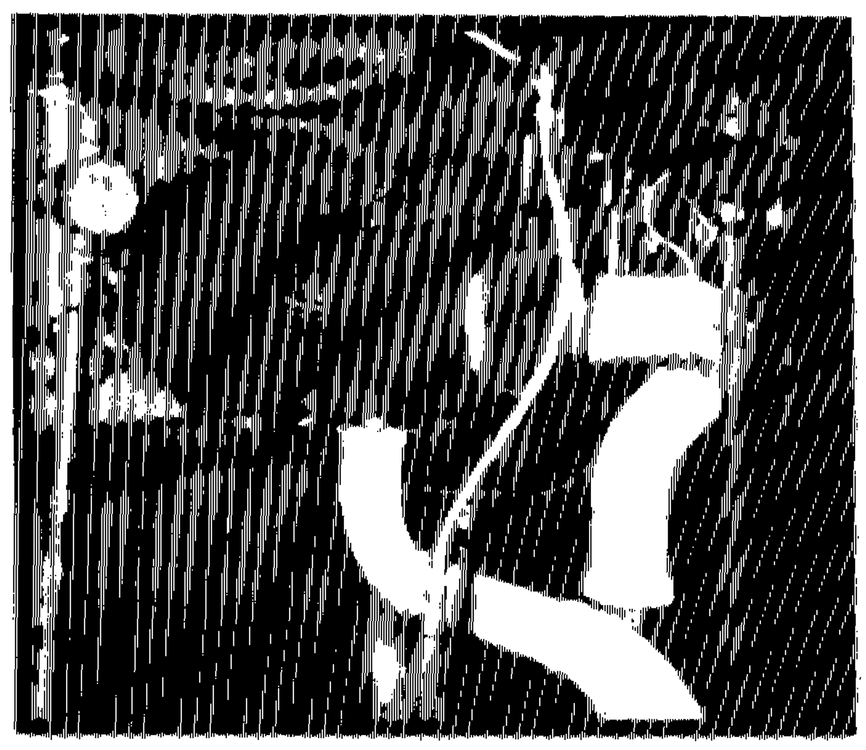


Figure 3: A TDI 56 Series starter mounted to an auxiliary gearbox (AGB) of a gas turbine [9]

The starter basic specifications are shown in Table 2:

Table 2: Basic Specification of TDI 56 Series Starter [9]

Model	**56G**
Engine	General Electric LM 1600 and LM 2500
Weight	21.8 kg
Air/Gas Supply	Compressed Air or Natural Gas
Pressure	10 Bar (max)
Power	165 hp on compressed air
	210 hp at 10 Bar on natural gas

2.3 Start Sequence

The sequence of events will follow similar pattern:

1. The gas turbine needs to be rotated up to a speed where the ignition system will start the igniters operating.
2. Once the igniters are operating and the engine has accelerated a little further up the rpm range the fuel can be metered to the combustion chamber.
3. The gas turbine should then be able to accelerate up past the speed where the igniters will cancel with or without starter assistance.
4. At some point during this acceleration, the starter will cut-out and the engine will proceed until it reaches the idle speed.
5. Once at this idle speed it is usual to sustain it for a short time (a couple of minutes) to allow the gas turbine to heat soak and allow the engine components to stabilize at the running temperature.

The summary of the startup trend are shown in Figure 4.

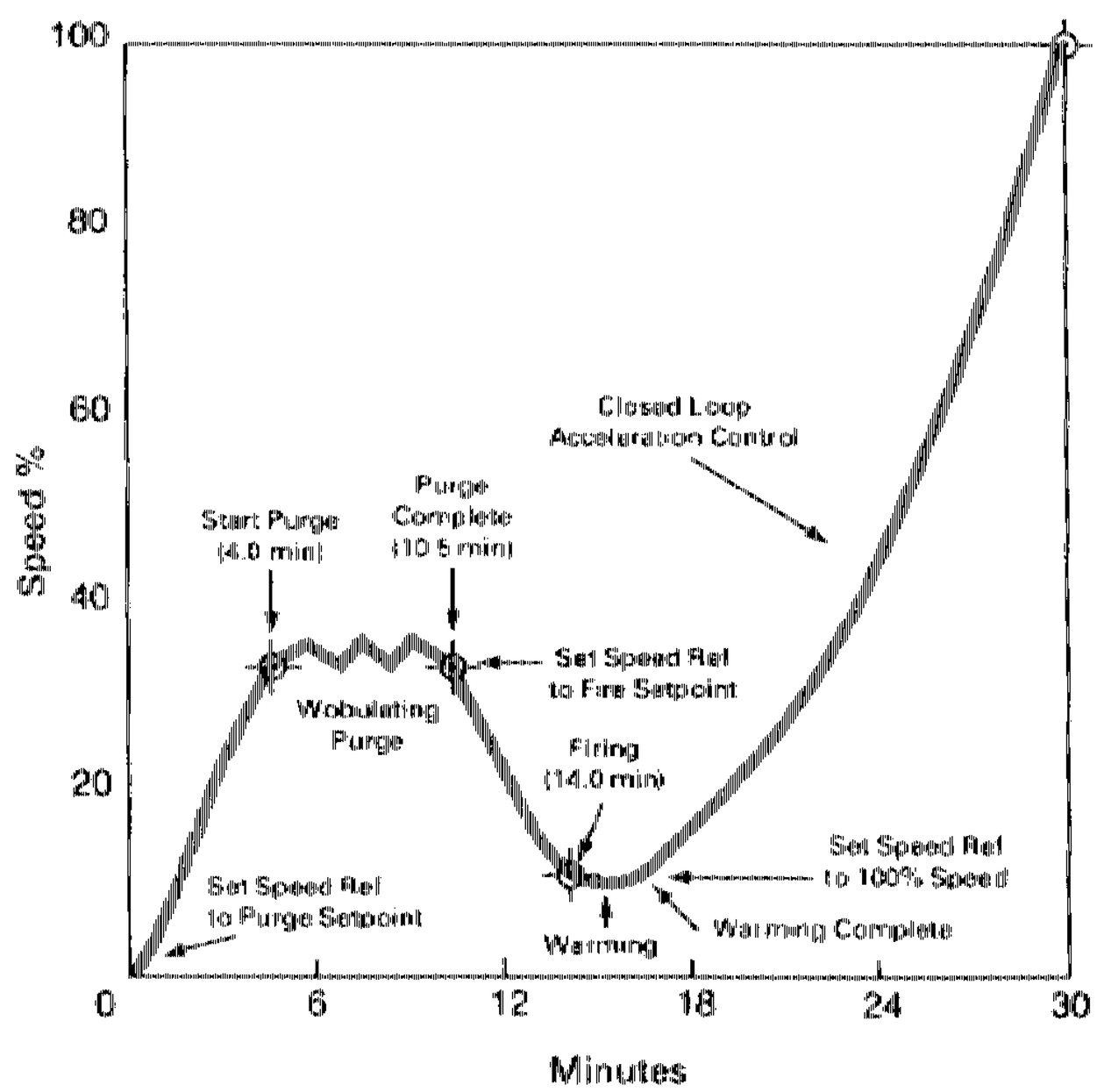


Figure 4: Typical startup sequence for gas turbines [3]

2.4 Failure Reporting, Analysis and Corrective System (FRACAS)

Failure Reporting, Analysis, and Corrective Action System (FRACAS) is a closed-loop feedback path in which the user and the supplier work together to collect, record, and analyze failures of both hardware and software data sets.

The user captures predetermined types of data about all problems with a particular tool or software and submits the data to that supplier. A Failure Review Board (FRB) at the supplier site analyzes the failures, considering such factors as time, money, and engineering personnel [4]. The resulting analysis identifies corrective actions that should be implemented and verified to prevent failures from recurring. A simplified version of this process is shown in Figure 5.

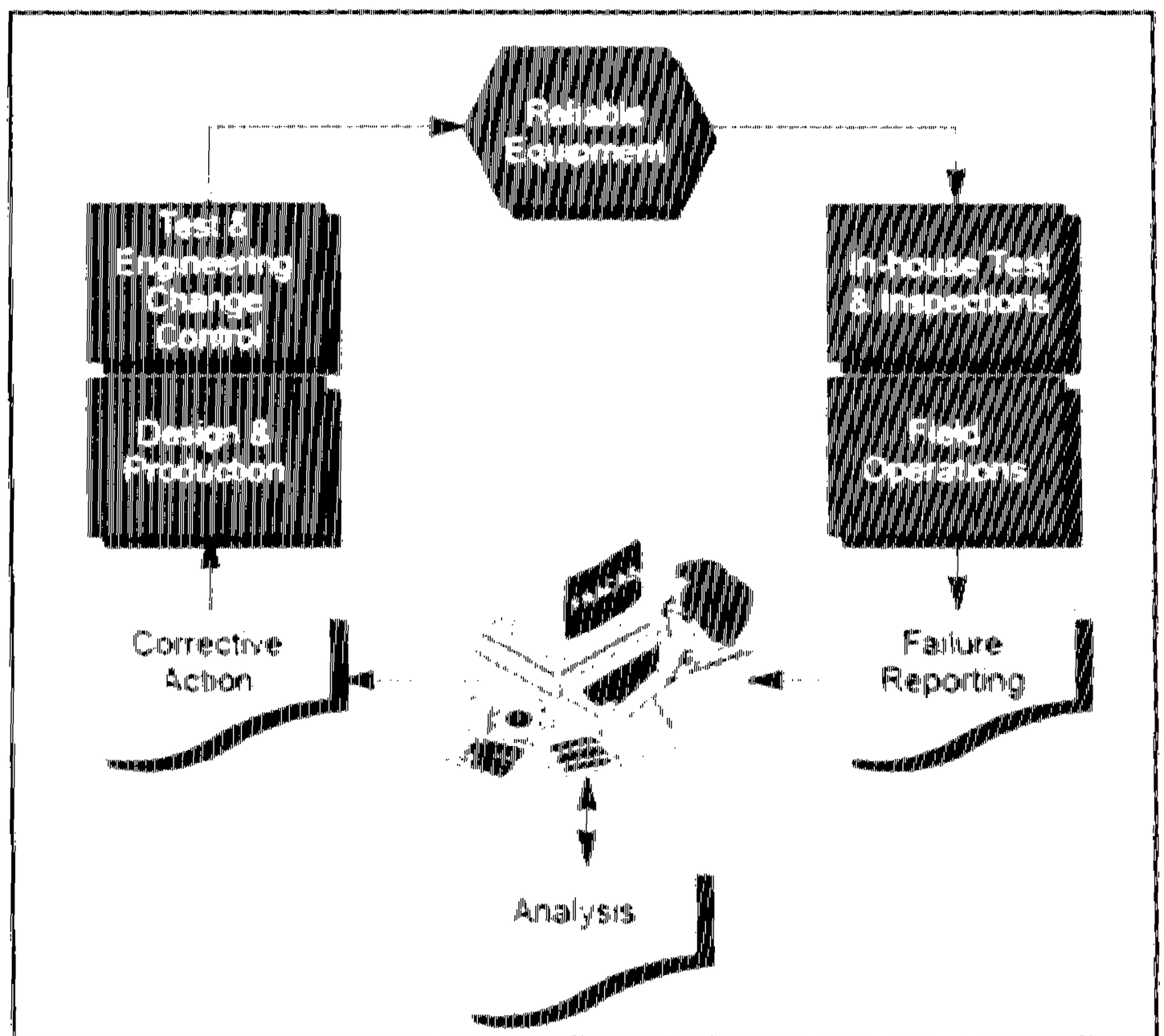


Figure 5: FRACAS Process [4]

2.5 Journals from previous research

The following shows previous research journals that have been encountered throughout the background study research as in Table 3.

Table 3: Review on Previous Journal

No.	Authors/Title/Findings	Relevancy of the journal to FYP
1.	Swati Biswas, M.D. Ganeshachar, B.R. Sridhar, S.Ramachandra, Failure Analysis of an Air Turbine Starter, Springer, Journal No 10:259-263 , 2010. Findings: i. In this study, the failure analysis of the starter's rotor had been done in order to recognize what is the main reason behind the failure. ii. The problem occurred during startup; a loud noise and sudden burst of sparks below front side of the engine were observed. Startup was immediately stopped. iii. Visual and stereo observations shows that : a) Rotor blade were heavily damaged b) Shaft connecting the rotor disc and sun gear were fractured c) Beach marks on rotor disc shows failure by fatigue crack propagation iv. Final analysis of the result shows that the fatigue failure may cause the blade failure. Blade failure might have led to blade tip rubbing with casing, which in turn causes restricted shaft rotation leading to failure by overload.	i. This research material is so closely related. The damaged component of the equipment was the same as this project. ii. The tests and observation in this research paper is relevant with the problem encountered. iii. However, this research paper didn't exactly discuss about the system's performance (i.e. gas inlet pressure). iv. Other than that, this particular starter was used on an aircraft engine, rather on a land gas turbine, which may have slight difference in terms of performance and maintenance activities.

No.	Authors/Title/Findings	Relevancy of the journal to FYP
2.	Jian Hou, Bryon J.Wicks, Ross A. Antiniou, An Ivestigation Of Fatigue Failures Of Turbine Blades In A Gas Turbine Engine By Mechanical Analysis, Pergamon, Journal No 201-211, 2002 Findings : i. In this case study, finite element analysis was used in order to recognize the main cause of the failure. ii. Examination from the failure blade indicated primary fracture by impact due to tip rubbing (from wear marks on the blade). iii. Tip wear occurred exclusively on most of the retired blade, irrespective of service time. iv. The paper concludes that blade failure occurred due to LCF (low cyclic fatigue) and HCF (high cyclic fatigue) as a consequence of tip rubbing impact. v. It's also concludes that centrifugal load, thermal expansion and gas pressure during steady state operation does not have a significant effect on crack initiation.	i. Failure occurred due to tip rubbing which were similar to the project's anticipated main cause of the failure. ii. But in this case, the fact that gas turbine blades material and geometry are different than starter turbine blades, this might result difference in the impact and damage on the blade. iii. Still for the project, the listed parameters that it's effect were denied, should be reconsidered, as this might leave a huge impact on a starter rotor

No.	Authors/Title/Findings	Relevancy of the journal to FYP
3.	A.G. Pascoe, Start Systems For Aero Gas Turbines, Emerald Group Publishing, Journal No 448-454,2005 Findings : i. This paper is an overview of aero gas turbine engine starting systems and discusses the system design considerations and integration with other aircraft systems. ii. This paper also aims to provide an introduction to modern gas turbine engine starting system. iii. It's also provides basic information on starter types and their limitations, and why some starter types are more favored in modern installations.	i. Pneumatic starter, which are going to be used in this project, are discussed in this paper in terms of characteristics and operation. ii. Relatively similar starting sequence are discussed in the paper, however, there is some differences since the starting sequence are for an aero purposes rather for a land purposes.

No.	Authors/Title/Findings	Relevancy of the journal to FYP
4.	Maria Vilacourt, Failure Reporting,Analysis, And Corrective Action System (FRACAS),Sematech,1994 Findings : i. A Failure Reporting, Analysis and Corrective Action System (FRACAS) is a system, sometimes carried out using software, that provides a process for reporting, classifying, analyzing failures, and planning corrective actions in response to those failures. ii. Analysis consisting wide array of information and results analysis such as failure report, failure review, corrective action and post data review.	i. This method is quite similar to the method of analysis of this project. ii. From the paper, data collected will be analyzes and cross referenced to equipment maintenance and status history, which were intended to be carried out for this project

Chapter 3

Methodology

3.1 Project Methodology

The small flow of activities planned for this project is shown in Fig 6.

Problem will be identified as project initiation

Past research papers will be studied for better understanding of the problem as well as method/ways to troubleshoot the problem

All failure during inspections and test are recorded and reported.

Failure analysis are conducted to determine the root cause of the failure

Development of corrective action plan, to eliminate or reduce recurrence of the failure.

Decision and data from previous action will be documented in final form of a report.

Figure 6: Project Methodology process flow

3.2 Data Analysis

Shown below in Figure 7 is process flow for failure analysis process.

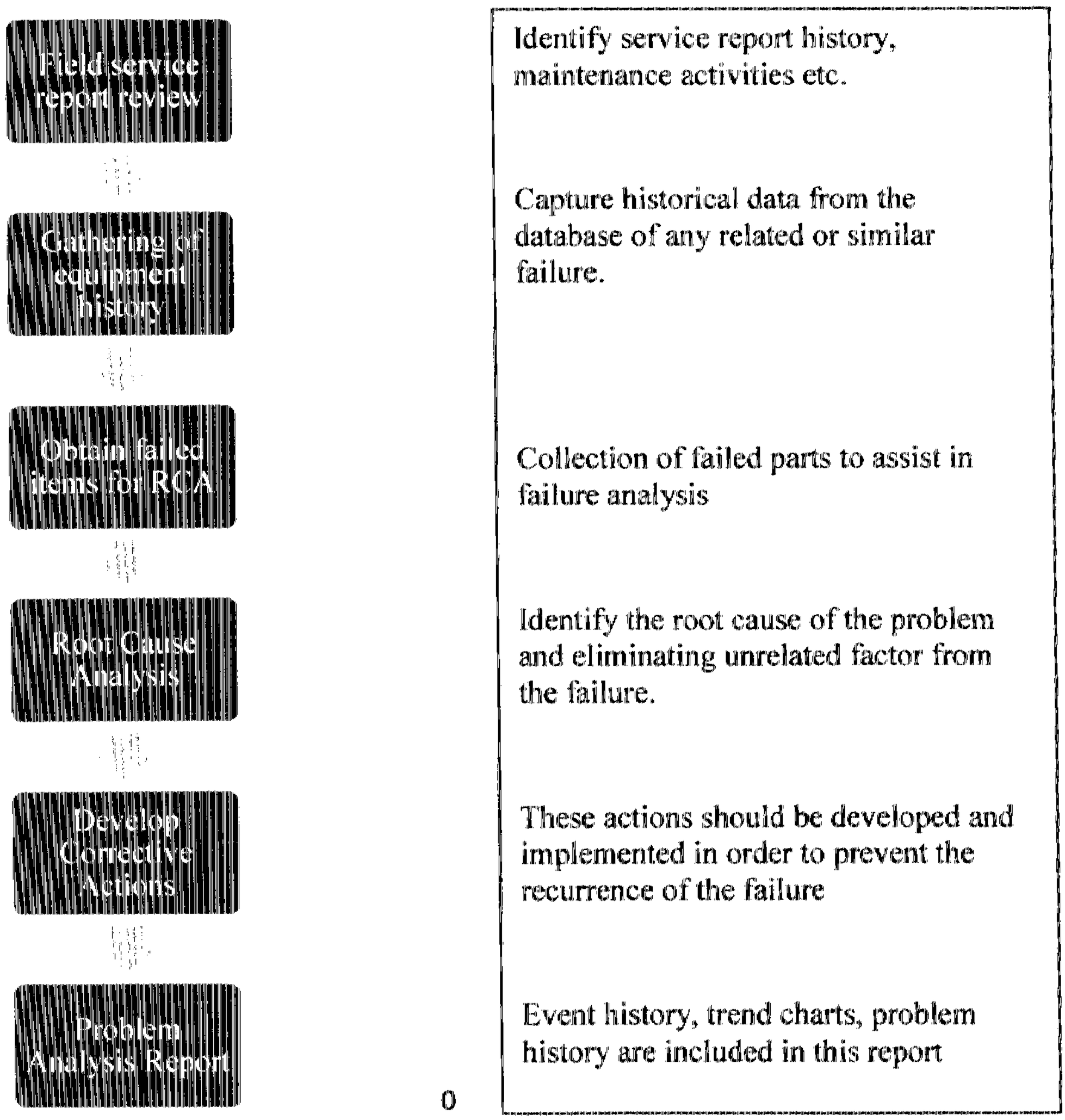


Figure 7: Failure Analysis Process Flow

3.3 Tools, Equipment and materials

There might several materials and equipments needed specifically for the experiments which are listed below:

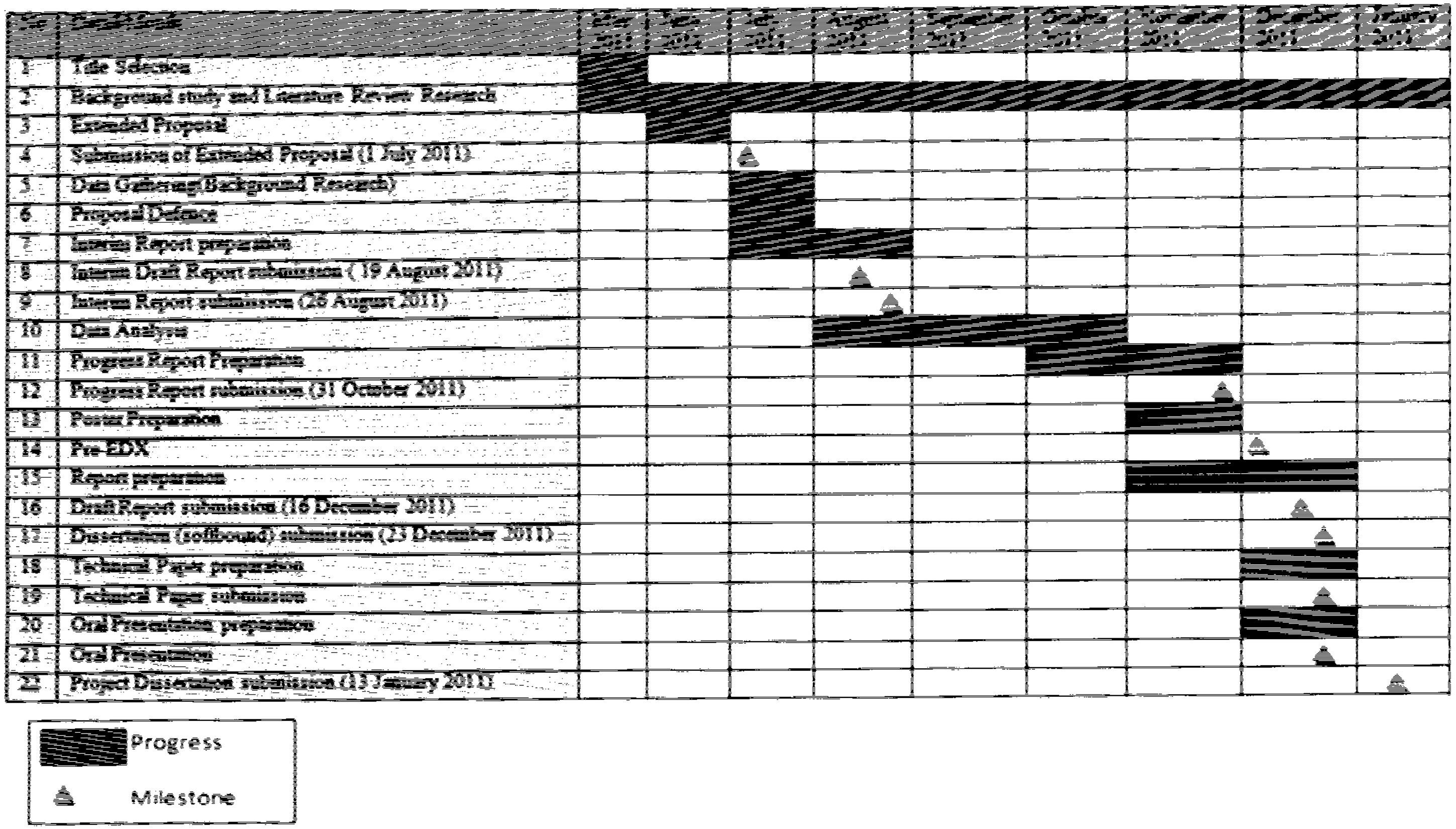
1. Pneumatic Starter (TDI 56 G Series)
2. Distributed Control System (Dresser Rand Evision)
3. Industrial Borescope (Olympus IPLEX FX)
4. Hand tools for teardown inspection
5. Digital Camera
6. Documents and reports related to the starter incident (provided by Petronas Gas Berhad)

There might be other materials or equipments will be added along the completion of this project.

3.4 Gantt Chart

Gantt chart below illustrates the start and finish dates of the terminal elements and summary elements of the project, as shown in Table 4.

Table 4: Gantt chart for FYP 1 and FYP 2



Chapter 4

Result and Discussion

4.1 Data Gathering and Analysis

4.1.1 Equipment Specification and History

Below are data and information of the effected starter and as for the image of the starter can be seen in Figure 8.

Figure 8: TDi 56 G starter in K6-0501A unit.

1. Equipment : Gas Turbine Aero Starter
2. Manufacturer : Tech Development (TDi)
3. Model : TDi 56 G
4. Serial Number : 0703 0317
5. Unit : K6-0501A
6. Installation Date : 15-12-2010
7. Status : Brand New
8. Failure Date : 11-03-2011
9. Number Of Startup (Prior to failure) : 9

4.1.2 Sequence of Event

Background data collection, as for this case study, will be referring to field service report review and equipment history as provided by PETRONAS Gas Berhad. From the field service report the starter failure occurs as this sequence as shown in Table 5.

Date	Time	Event
11-03-2011	0542	K6-0501B was tripped due to "Rupture Disc Burst"
11-03-2011	0557	MRB engineer was informed about the trip. Operation decided to start K6-0501A
11-03-2011	0610	Shift Supervisor informed K6-0501 having lube oil splash onto the package
11-03-2011	0615	MRB technician was informed about the situation and deployed to site
11-03-2011	0652	MRB instrument rectified the site condition. Decided to make good K6-0501B as the oil splash is more severe
11-03-2011	0900	MRB start to investigate the oil leak source. Perform starter replacement and tested.

Table 5: Lube oil leak thru starter sequence of event table [III].

As from this sequence of event, we can see that the failure initially detected as "Rupture Disc Burst" which can be assume as overpressure in the line, as for in this case the fuel supply line to the starter, however, this assumption are just preliminary and intuitive without justification of any proven tests and analysis.

4.1.3 Data Evaluation

The recorded startup curve, in this case the recorded curve were the startup process which take place prior to the startup with starter failure, in the DCS panel was analyzed and some anomalies were detected. The recorded startup curve is shown in Figure 9.

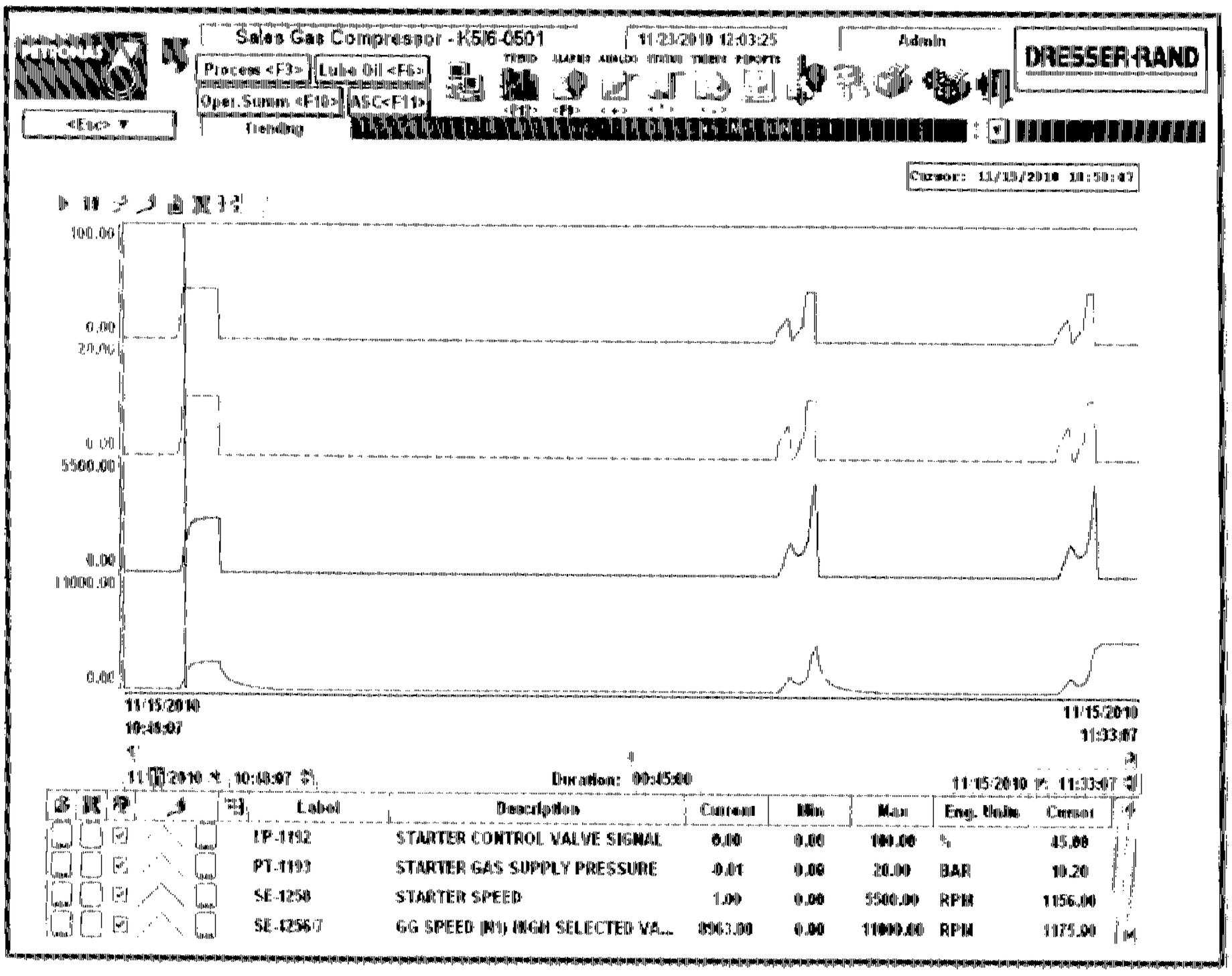


Figure 9: Startup curve for K6-0501A.

1. Starter Gas Supply Pressure and Valve Signal (Green and Red Line).

   The gas supply pressure for the starter peaked at 11.50 bars and valve signal opening at 50.47%

2. Gas Turbine and Starter Speed (Blue and Purple Line).

   Gas turbine failed to start at first attempt. Startup was successful at second attempt.

4.1.4 Site Evaluation

From these images below, it can be concluded that the failure did occur due to overpressure as stated in the event sequence above. During the site visit, lube oil are to be found everywhere near the gas turbine housing as shown in figure 10, 11 and 12.

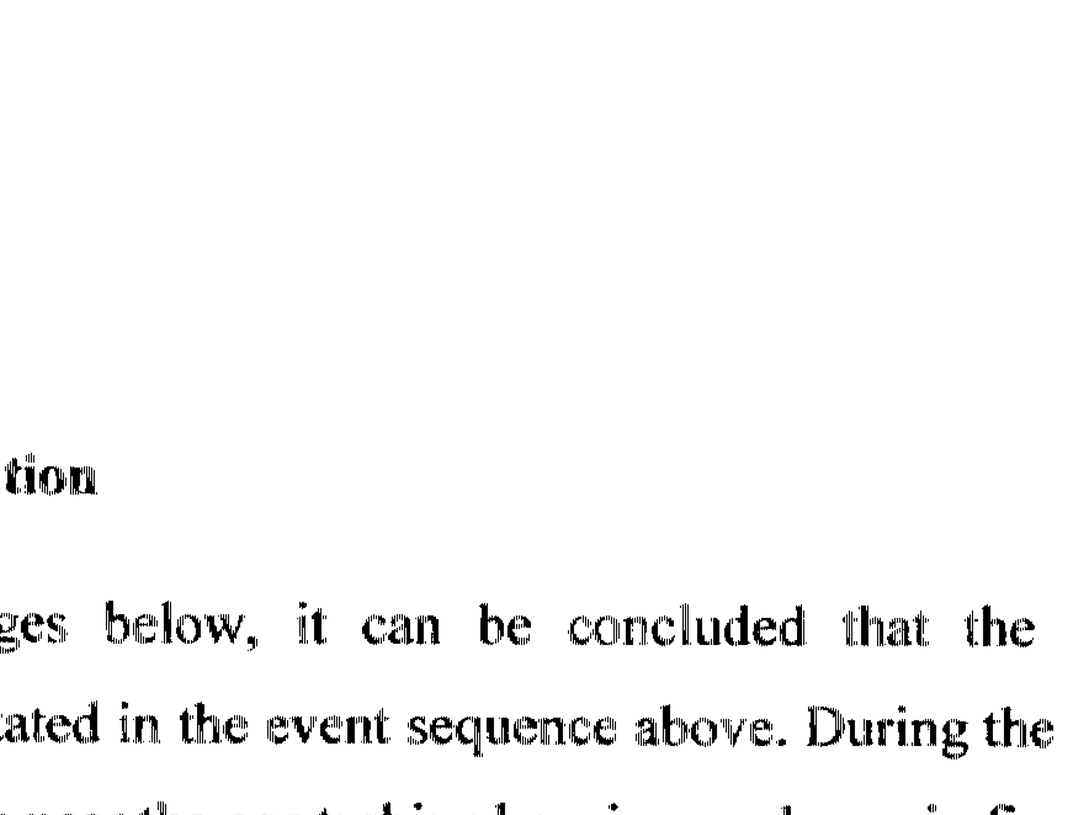


Figure 10: Lube oil spill 1 (on the floor of Unit 5 near K6-0501A turbine housing) [11].

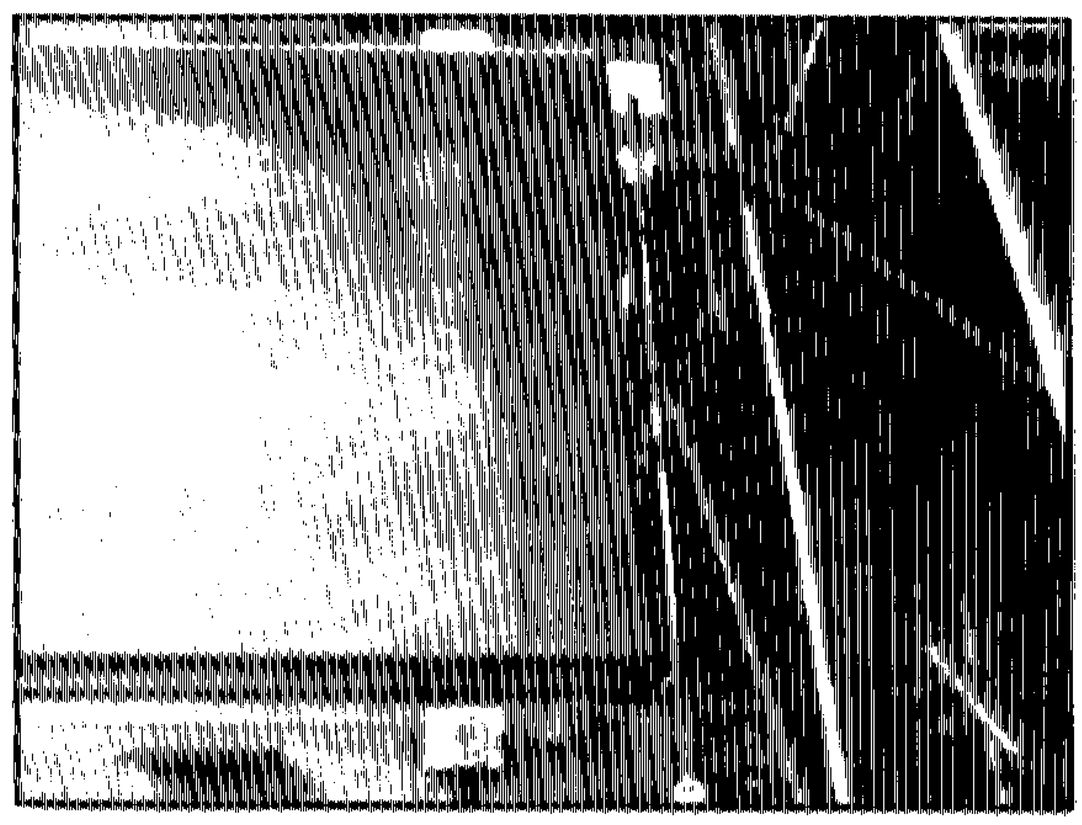


Figure 11: Lube oil spill 2 (on the turbine house filter of K6-0501A, view from inside of the turbine housing units) [11].

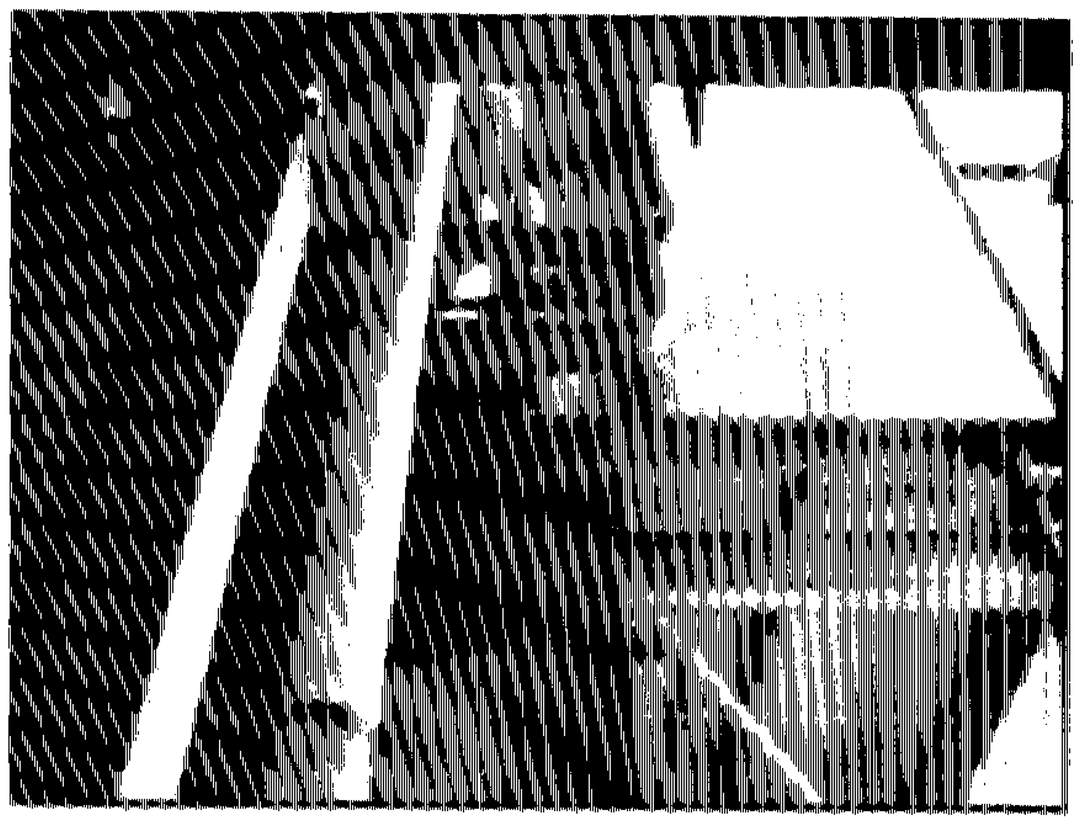


Figure 12: Lube oil spill 3 (on the turbine house filter of K6-0501A near the air inlet)

Initial conclusion after site evaluation shows that the lube oil bursts from somewhere above K6-0501A turbine housing, as large area of lube oil spill was found near the turbine housing unit and a large amount of lube oil spill above the turbine housing unit.

4.1.5 in Situ Inspection

In site inspection was carried out in order to pinpoint the actual error or failure that causes this incident to happen based on site evaluation. The Piping and Instrumentation diagram for gas turbine with starter unit are shown in Figure 13.

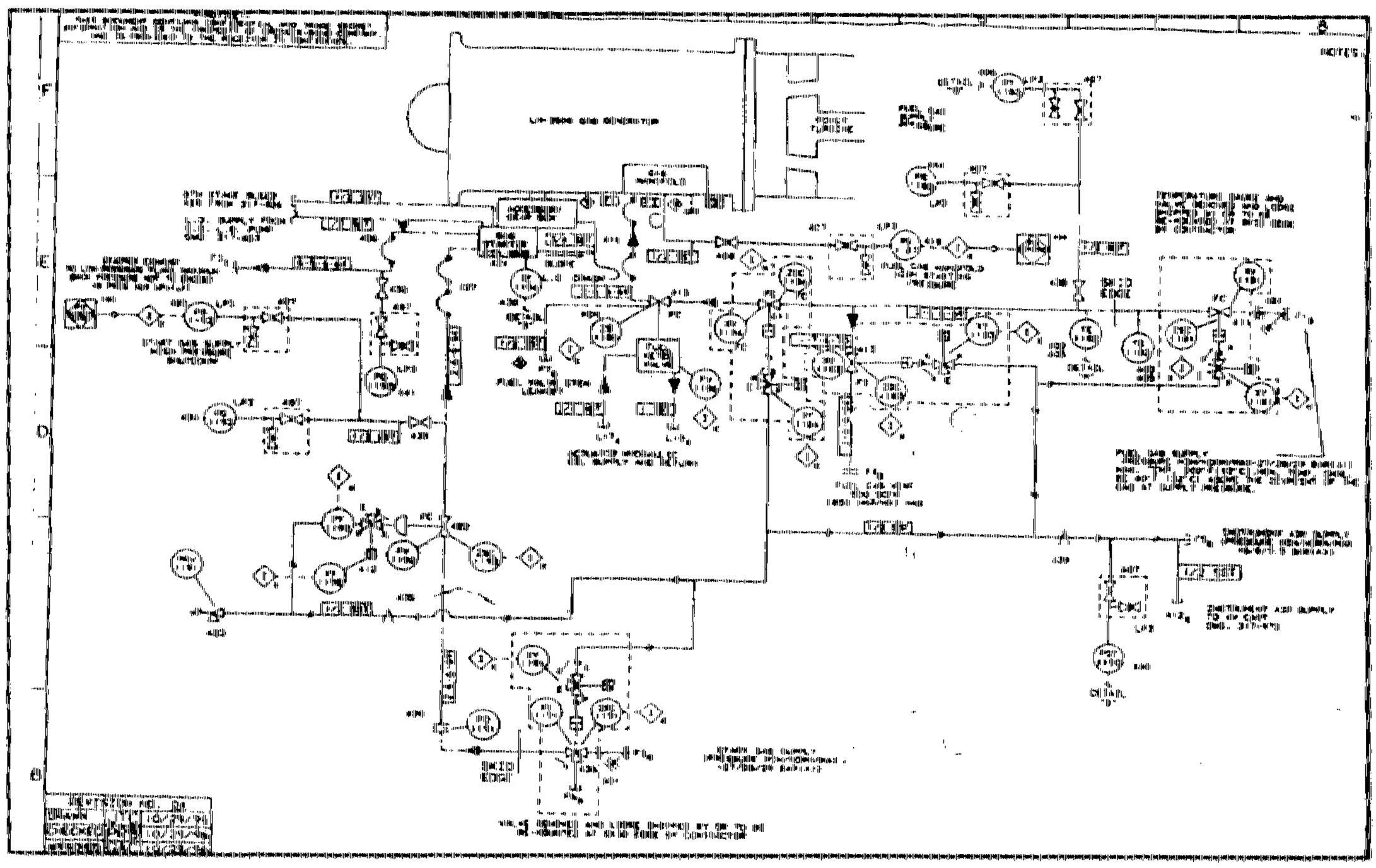


Figure 13: Piping and Instrumentation Diagram of K6-0501 A starter system.

From the diagram above, there were two possible piping lines that can be associated with lube oil which is:

1. Starter Gas Supply line (Tag number 2.6.6.64)

   This line provides the starter with the pressurized gas, as fuel, from the plant piping system. AS shown in the diagram, the pressure from the system reads at 28 BarG on normal reading; however the pressure were, by sequence, reduced by:

   a. An orifice plate (Tag: FO-1192).
   b. A gate valve (Tag: PY-1192) which is controlled by a 3 way globe valve (Tag: XV-1192).

2. Starter Exhaust line (Tag Number 6.5.6.64).

   This particular line acts as an exhaust line for the starter, as stated in the diagram it was feeded to the flare line for flaring purposes. As shown in the diagram, the pressure to the line peaked at 10 BarG. The line pressure were controlled by a gate valve (Tag: 438) in order to stabilized the pressure to the flare line.

Since the department has experienced the same problem symptoms but with different brand of starter, they decided to check 2 possible leak path which is [11]:

1. The starter system.

   The exhaust line is one of the ways that lube oil can leak thru. The exhaust line serves as exit line for Low Pressure fuel gas, produced by the starter as waste, into the atmosphere. By this fact, if seal failure or component failure occurs inside the starter, there is a possibility that the lube oil could run through the starter and into the exhaust line, causing the lube oil to be released into atmosphere. The exhaust line location and configuration are shown in Figure 14.

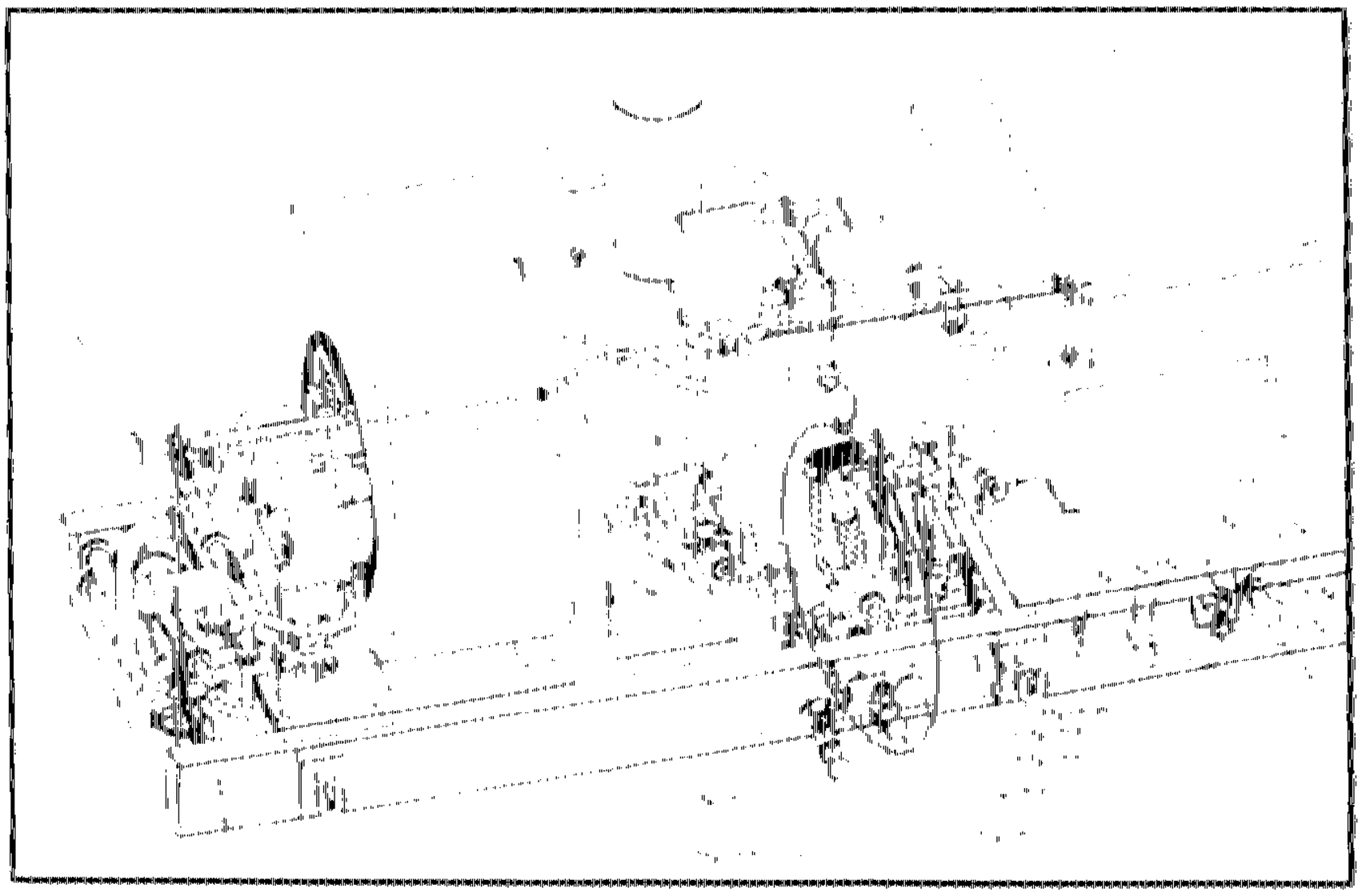


Figure 14: Starter system. LP fuel gas is discharged to atmosphere [11].

2. Air Oil Separator System.

Air Oil separator is a component in a gas turbine lubrication system in which air is removed from scavenged oil before its return to the oil tank. The scavenged oil is churned, resulting in air coming to the surface, which is then bled out before returning the oil to the tank [7].

As for this case, the department suspected this line due to its heavy association with lube oil. The leak source maybe from the separated air discharge line and maybe the demister filter casing (as shown in Figure 15), since the location of the demister filter is on top of the turbine housing, judging from the area effected by lube oil, the department suspects that this is another possible leak path.

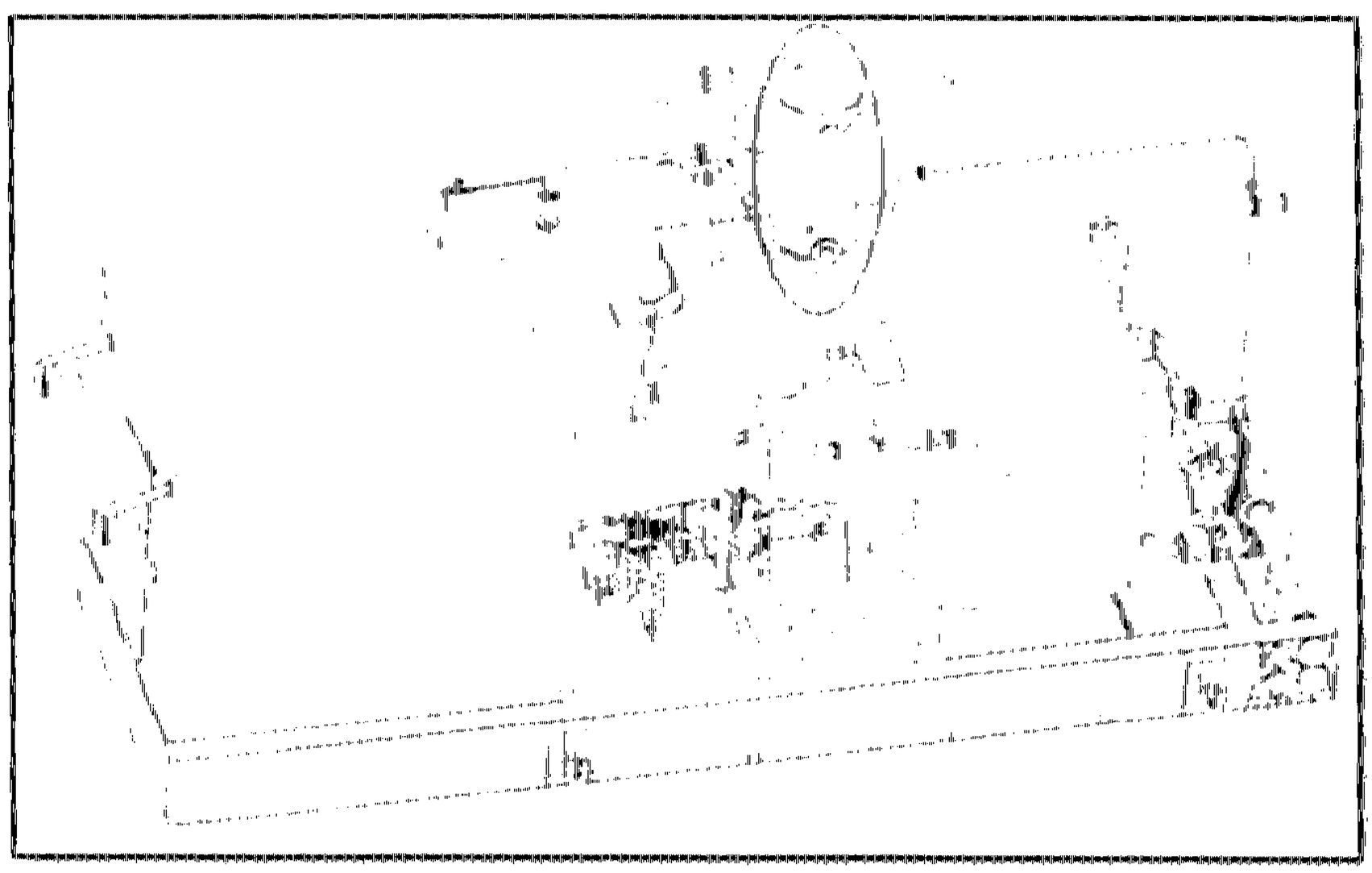


Figure 15: Air oil separator system. Separated air is discharged to atmosphere [11].

Before any conclusion was to be made, the department decided to run a visual inspection in order to pinpoint where the actual leak source is, by this they decided to run a borescope inspection inside both of the air oil separator system line and the starter system line. After the inspection was carried out, they didn't find any lube oil in the air oil separator system line, however they discovered oil residue in the starter system line [11]. The image from the starter exhaust piping in the starter system line is shown in Figure 16 and 17.

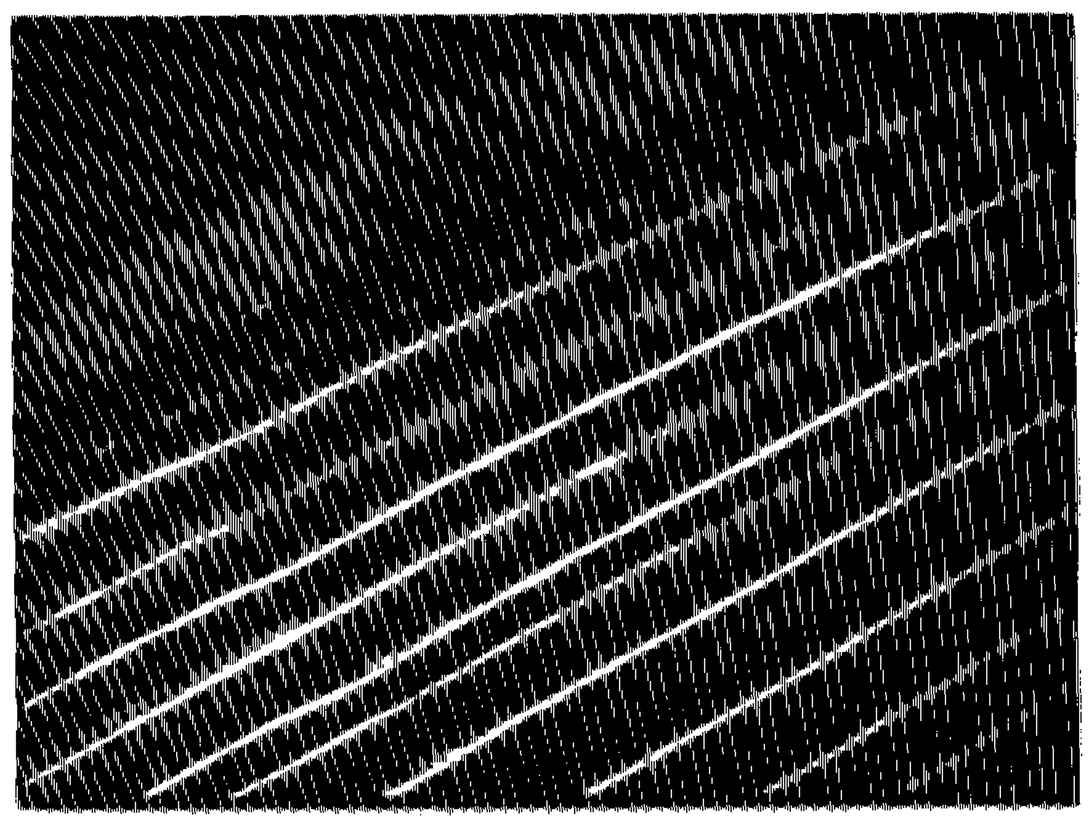


Figure 16: Lube oil traces in the starter exhaust piping [11].

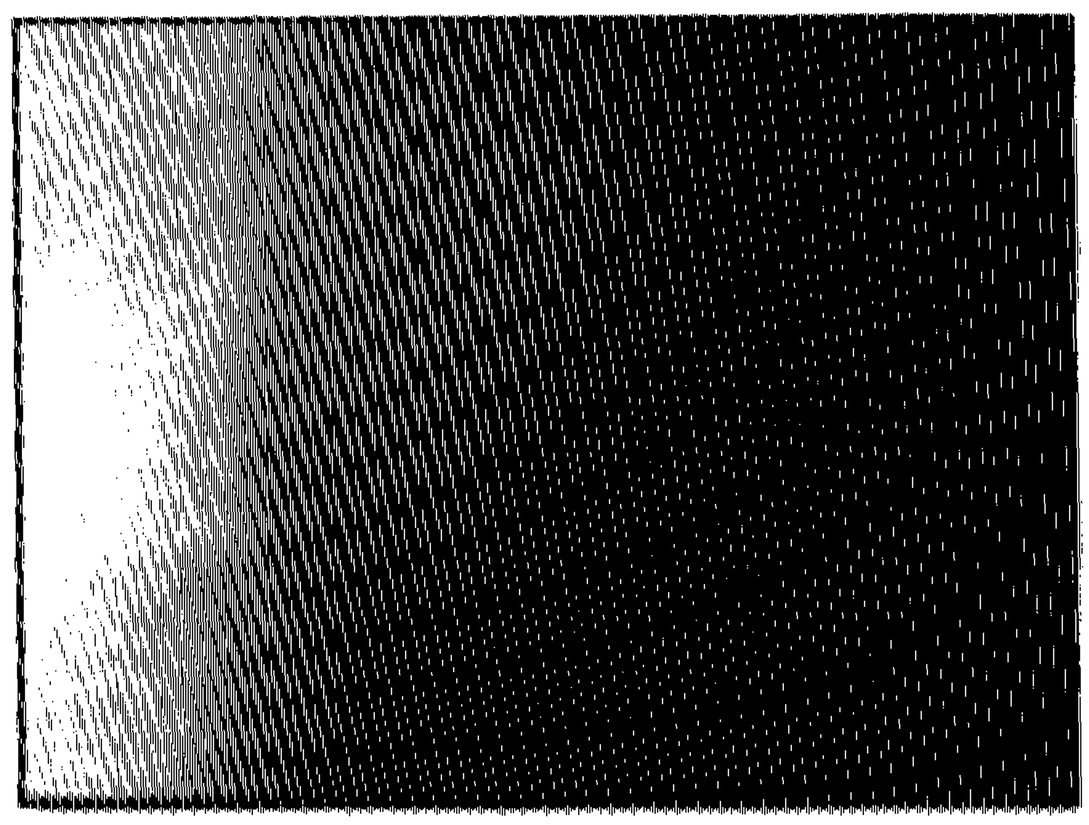


Figure 17: Lube oil residue in bottom of exhaust piping [11].

4.2 Tear-Down Inspection

A tear down inspection were decided to be necessary to detect the defective parts in the starter. Roughly, by visual inspection on the defective parts, the source or reason or the failure can be concluded. In this case, the defected starter was sent back to its representative service workshop (Barcol-air) which was located in Singapore. The inspection were carried by the workshop personnel, assisted and witnessed by MRB's personnel. Findings on the tear down inspection are shown in Figure 18, 19, 20, 21 and 22.

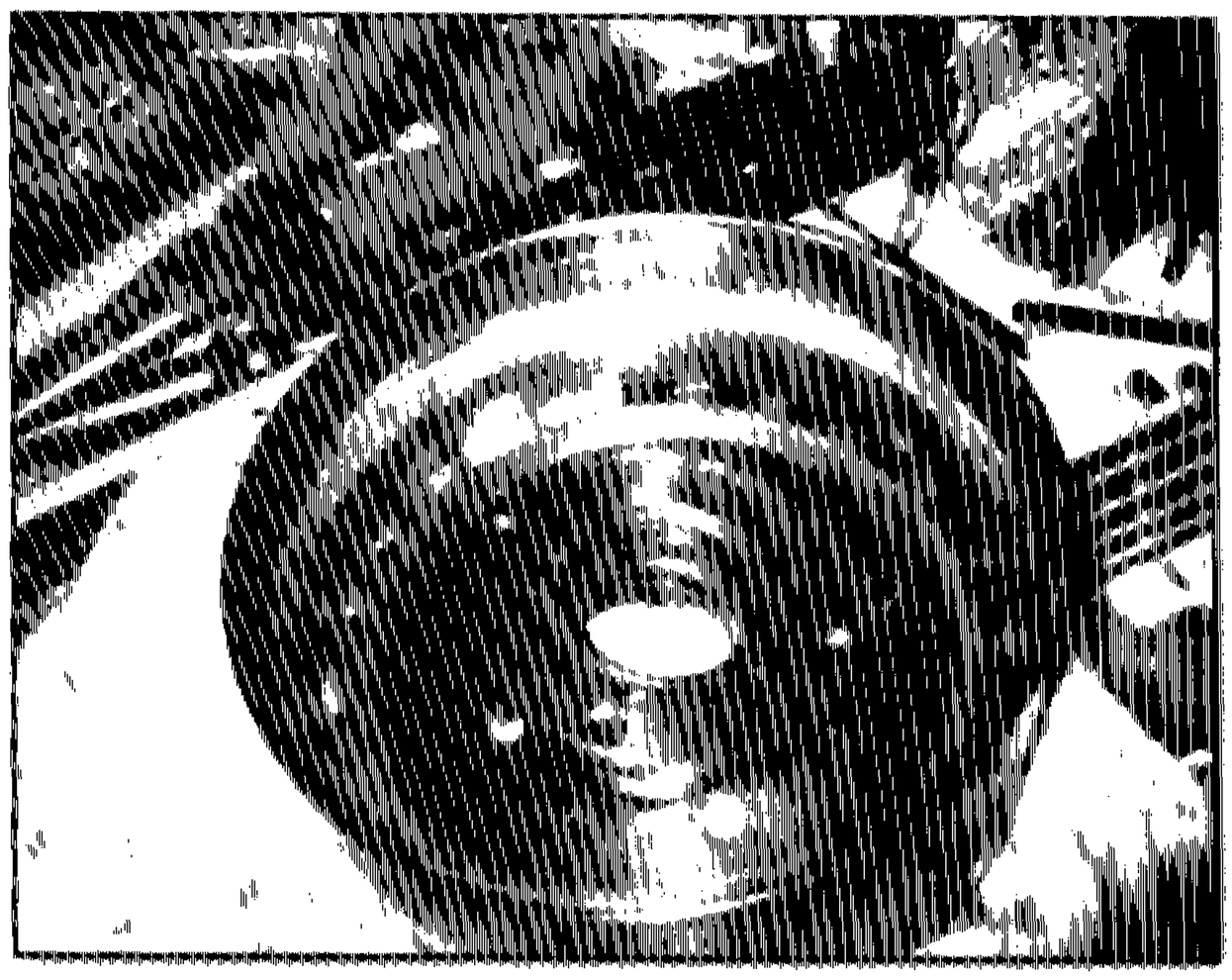


Figure 18: Worn Out nozzle liner (Part Number 21).

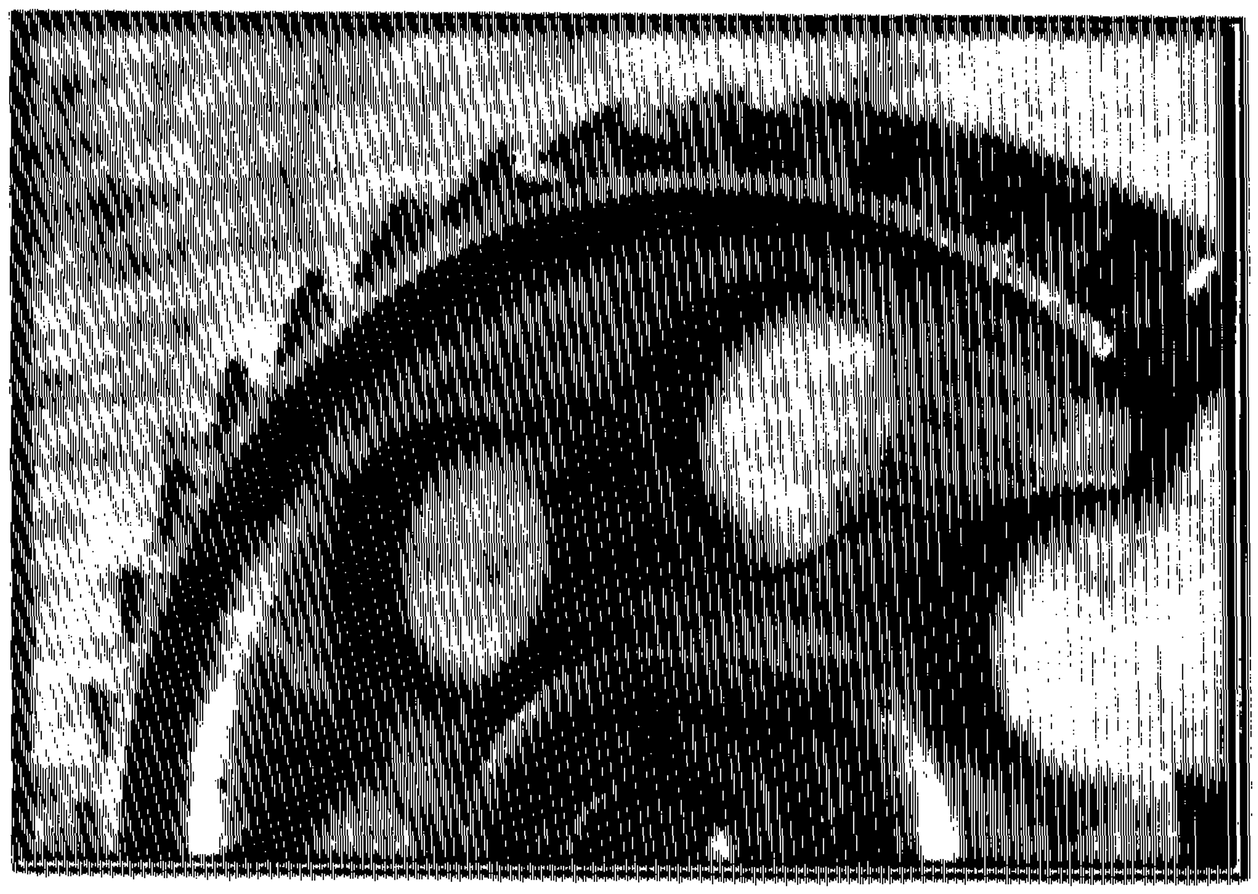


Figure 19: Broken Turbine Rotor (Part Number 6).

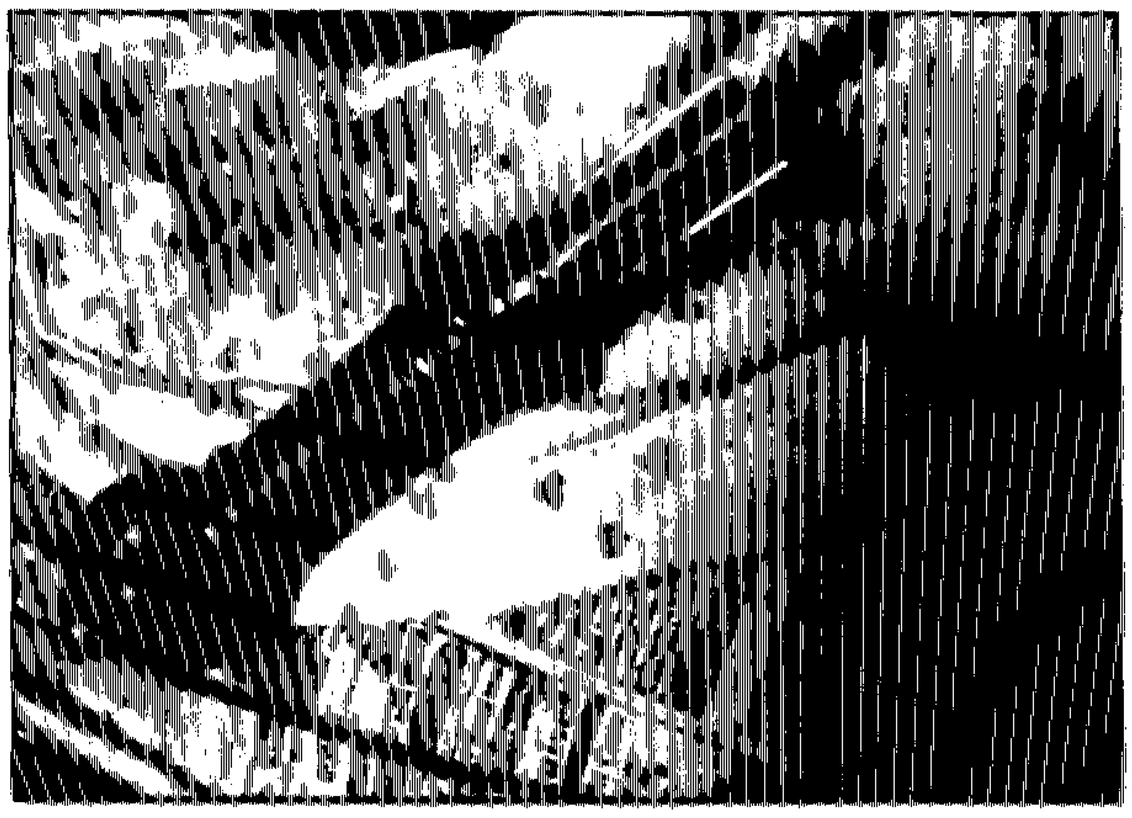


Figure 20: Heat marks on turbine shaft (Part Number 34).

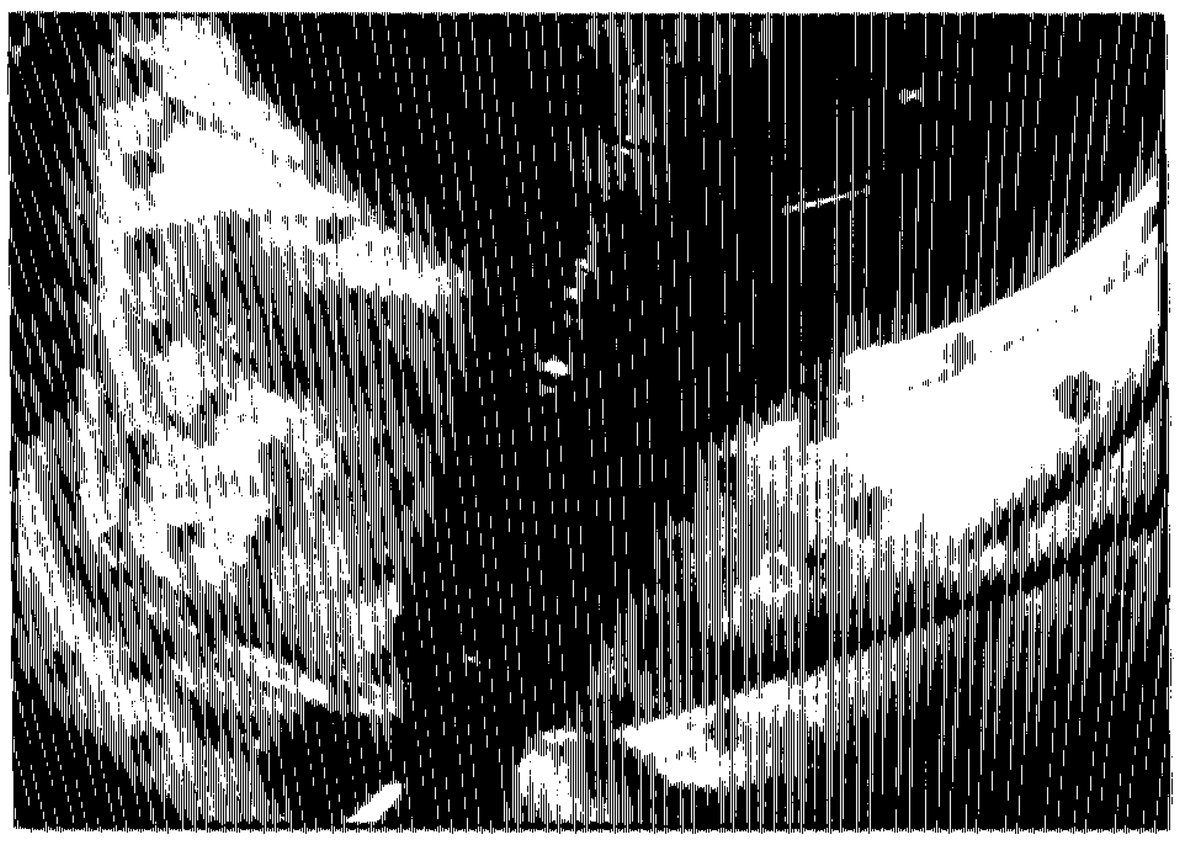


Figure 21: Broken Mating Ring (Part Number 11).

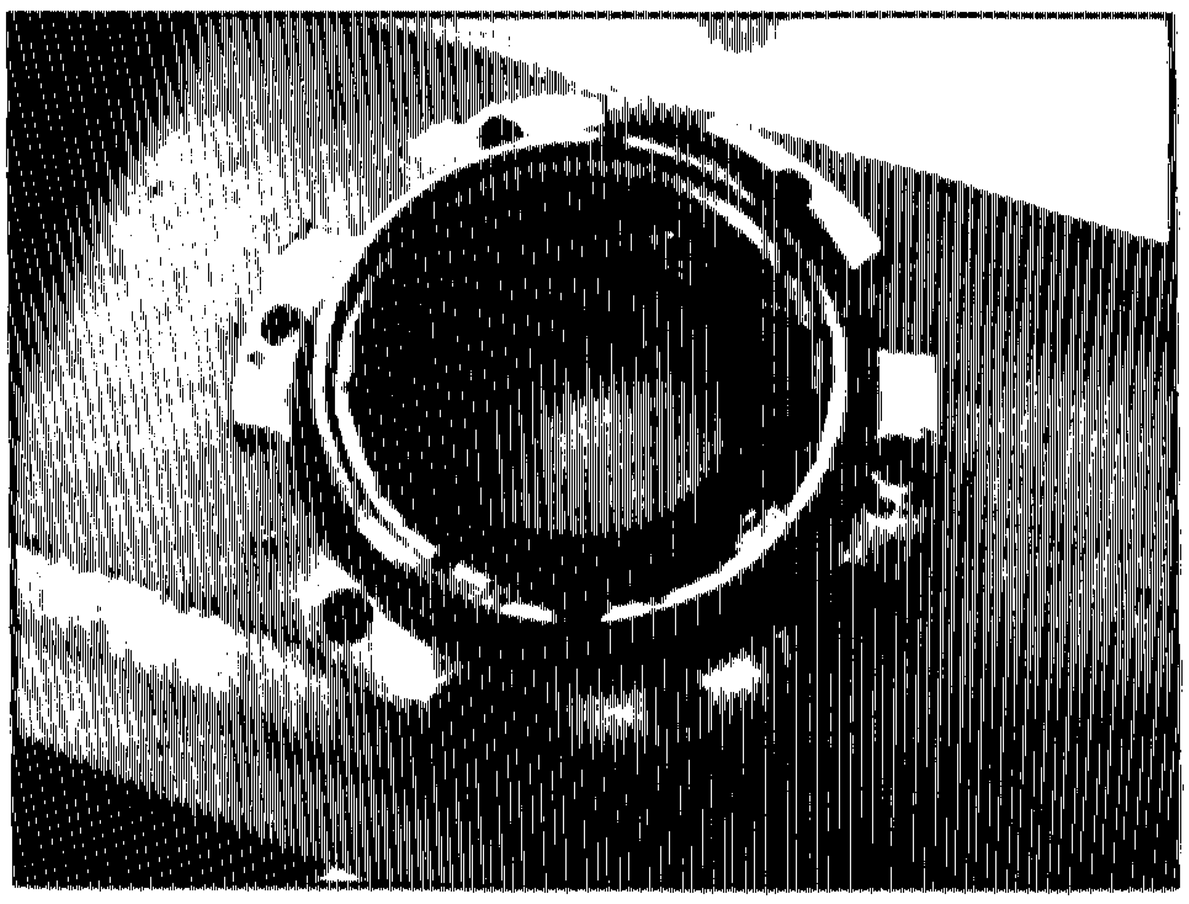


Figure 22: Damaged Seal Face (Part Number 13).

From the images above, all the defective parts are parts to be found in the turbine housing assembly of the starter, as there is no parts failure in other starter section. The parts number stated in the figure 18, 19, 20, 21 and 22 correlates with the parts number shown in Figure 22.

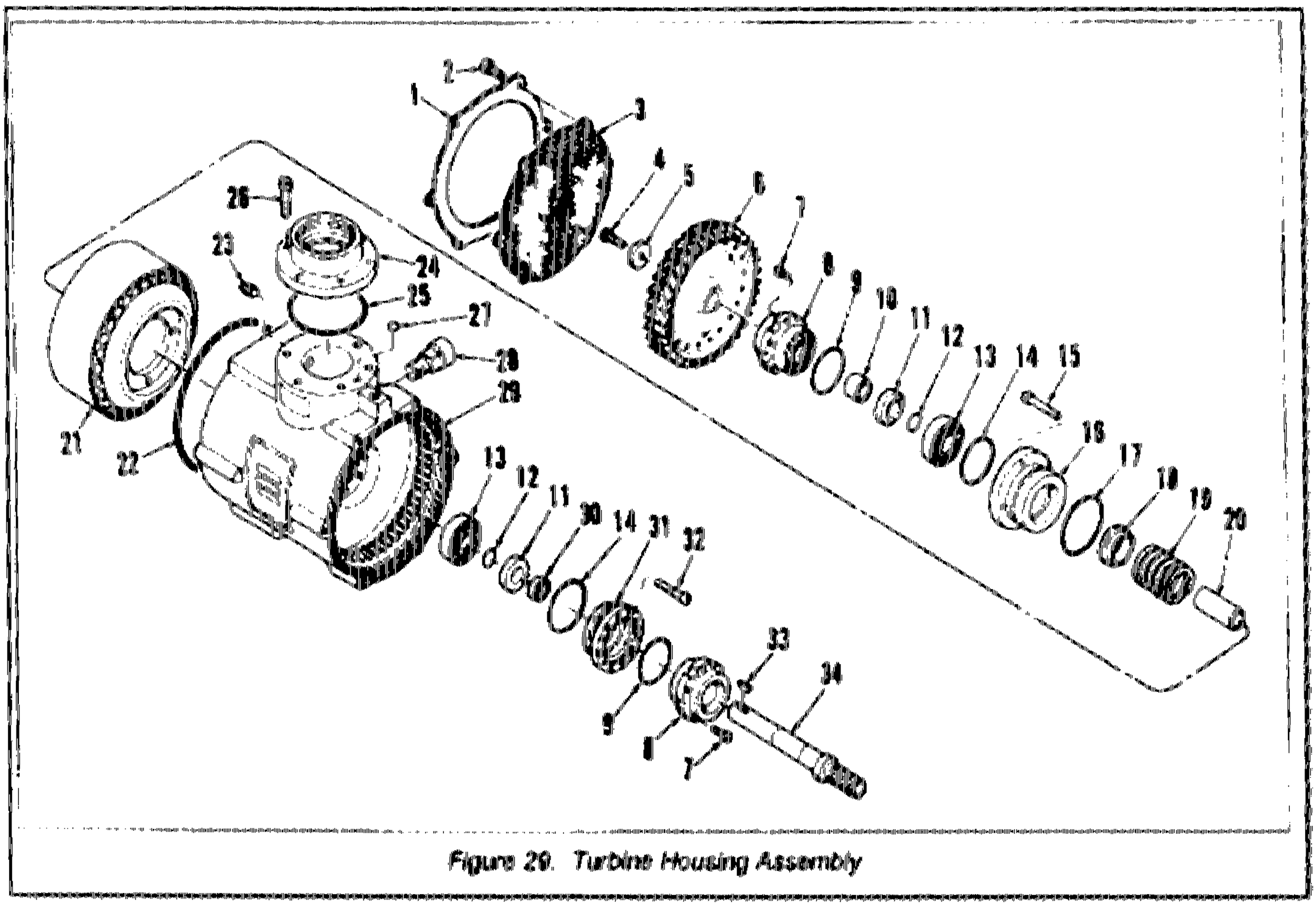


Figure 23: Turbine Housing Assembly.

From figure 22, it has been recognized that part number 6, 11, 13, 21 and 34 are damaged. From the defective parts that have been discovered, the sources or the main reason for each failure on the parts can be concluded.

4.3 Root Cause Analysis

With the information and details of the failure obtained, a root cause analysis is crucial in order to identify the main cause of the failure and came out with an action to prevent the failure from recurring again. The constructed root cause analysis diagram is shown in Figure 24.

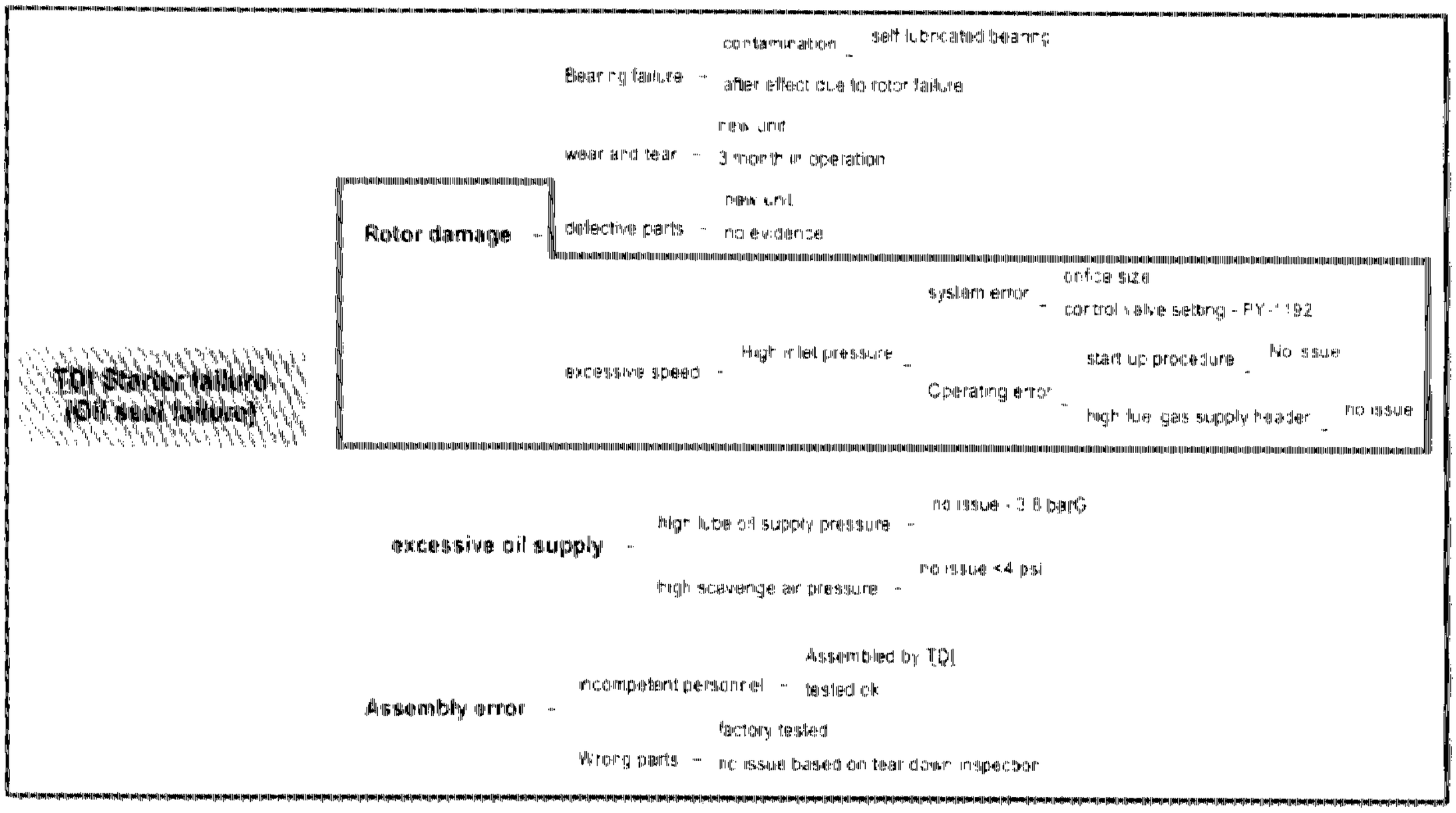


Figure 24: Root cause analysis of Tdi starter failure diagram.

The major analysis of the failure can be classified into categories which then narrowed down in order to pinpoint the actual root problem, which in this case follows:

1. Part Failure (Rotor Damage).

   Form the teardown inspection, it is discovered that the failure occurred in the turbine section of the starter, however, the symptoms and damage observed on the parts shows that there are few factors that causes damage to the turbine blade:

a. Bearing Failure.

Bearing failure may occur due to lube oil contamination; however in this case, the lube oil was sent to lab for analysis and final report shows that there was no evidence of contamination. Other than that, it failed due to effect triggered by the turbine after it was damaged earlier.

b. Wear and Tear.

Wear may contributes to this failure as it lowers the resilience and material properties of the parts, which in this case, rejected as the unit was only 3 months in operation.

c. Defective Parts.

Defective parts prior to operation may also be a factor, but in this case, it was rejected as the starter unit is a new unit from the manufacturer.

d. High Inlet Pressure.

High inlet pressure in this case may happen due to the operating error, which in this case poses no issue, and the system error. For the system error, earlier in the PnID diagram, the pressure control instruments (PY-1192 through XV-1192 setting) may have failed to control the pressure (Valve signal at 50.47% with inlet pressure of 11.50 BarG). This root problem was decided as the main problem of this failure as it satisfies the data and analysis gathered earlier.

2. Excessive Lube Oil Supply.

Lube oil are supplied to the starter through the main lube oil line for the gas turbine, however, two gauges were installed at the scavenge pump to detect lube oil pressure and scavenge air pressure, and it shows no abnormalities in the reading.

3. Assembly Error.

No significant analysis in the assembly error as the unit was manufactured and assembled by the manufacturer itself and visit to the service workshop proves that there no issue on assembly.

4.4 Corrective Action and Starter Replacement

From the root cause analysis, these corrective actions were carried out:

1. Reconfiguration of PY-1192 through XV-1192 valve setting.

   Logic verification of XV-1192 was decided necessary as it affects the performance and signal transmission for PY-1192 valve. This logic verification will be checked before and after every gas turbine startup sequence to ensure no repetition for this issue.

2. Orifice Plate (FO-1191) sizing.

   There's no issue on the upstream orifice plate sizing as the reconfiguration of valve XV-1192 are enough to satisfy the desired pressure drop for the starter.

Other than the steps above, some precautions actions were also taken out in order to verify the status of the starter system prior to startup.

1. Starter Inlet pressure.

   The inlet pressure should be maintained below 10 BarG which is the maximum operating pressure for the starter.

2. Scavenge air pressure verification.

   Scavenge air pressure reads at 4 Psi, which is normal.

3. Lube oil supply pressure verification.

   Lube oil supply pressure reads at 3.8 BarG, which is normal.

4. Periodic inspection on starter setting.

   Duration between inspection on PY-1192 and XV-1192 setting were shortened in order to improve starter reliability.

The recorded startup trending after applying the corrective actions and starter replacement are shown in Figure 25.

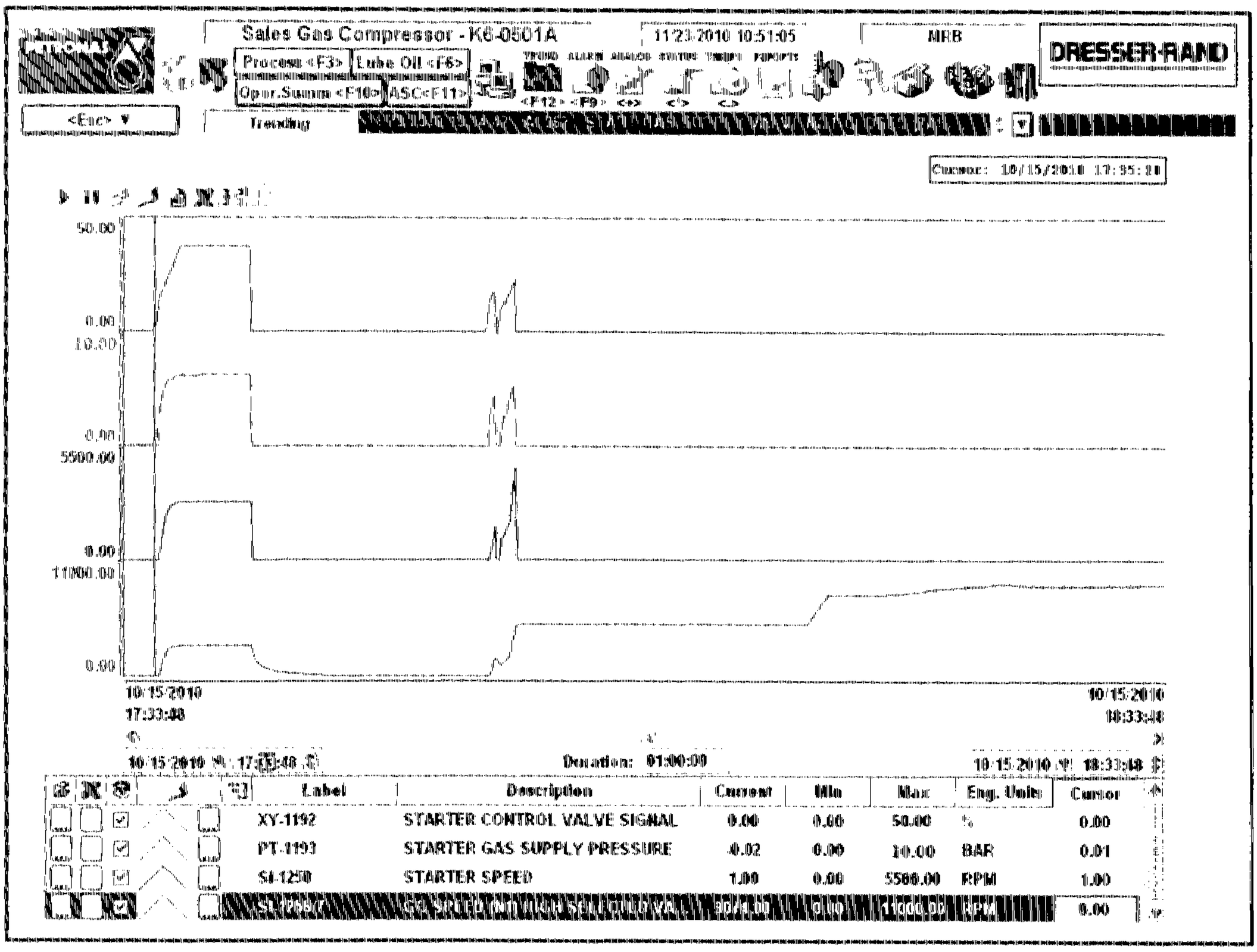


Figure 25: Startup curve for K6-0501A (After repair).

Information obtained from the trending above is:

1. Starter control valve signal (Green Line).

   Valve signal peaked at 42.19 % during purging process and at 29.37 % during startup. Valve signal is slightly lower compared to 50.47% before valve calibration.

2. Starter gas supply pressure (Red Line).

Starter gas supply peaked at 7.27 BarG during purging process and 6.83 BarG during startup. Gas supply pressure is lower compared to 11.5 BarG, before valve calibration.

3. Starter Speed (Blue Line).

   Starter speed peaked at 2869 rpm during purging process and 4452 during startup process. Speed remains consistent when compared to the startup trending before valve calibration.

4. Gas Turbine Speed (Purple Line).

   Gas turbine speed peaked at 2890 rpm during purging process and 4476 rpm during startup process. Gas turbine speed continues to accelerate to 9846 rpm to reach it operational speed. Speed remains similar, however, this startup only conducted once compared to the previous startup which requires two startup before the starter can successfully disengaged from the turbine.

In order to ensure they will be no similar problem happen with the serviced starter, they decided to monitor the lube oil reservoir level in case any sudden level drop occurs; this can be seen in Figure 26.

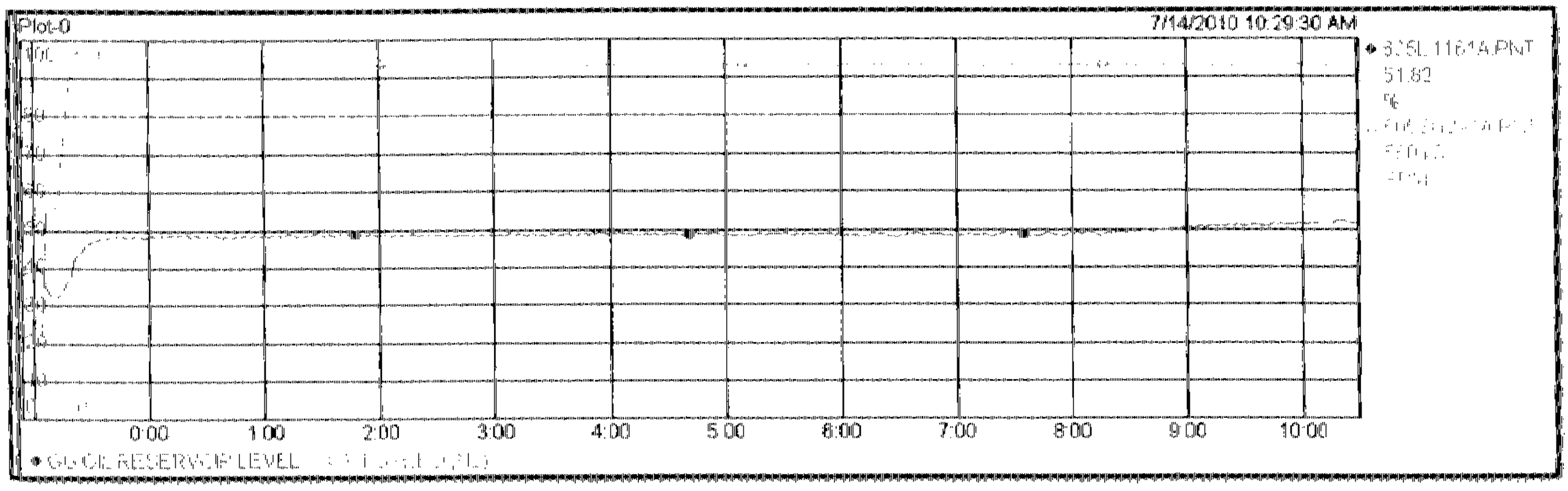


Figure 26: Gas Turbine lube oil reservoir level trending[11].

Trending from the lube oil reservoir shows that there was no sudden drop in lube oil level which indicates there's no leak occurs in the starter lube oil line. The startup process was successful and the turbine unit continues its operations as normal.

Chapter 5

Conclusion and Recommendation

5.1 Conclusion

As mentioned earlier, this project first objective is to study the failure analysis of gas turbine starter failure which in this case, came out with a root cause analysis with respect to the background and equipment data gathered in the earlier stage of the project. The data gathered was proven to be useful when it come to the root cause analysis as it provide vital information about the failure and highlight the actual problem for the failure. In this case the main cause of the starter failure is due to excess pressure which results from XV-1192 valve setting.

As for the second objective, it is to provide the corrective action for the failure. In this case, background study about the equipment history and data proven to be useful as normally, the problem came from either the equipment itself or the environment around it. By this, the corrective actions were successfully carried out and it's proven to solve the problem as indication and reading from the control panel shows no abnormalities. By this, XV-1192 valve setting was recalibrated and a shorter periodic inspection on the starter and valve configuration will be carried out.

5.2 Recommendation

Based on the results and conclusions obtained from this study, the following suggestions for future work in the same area are recommended:

1. Detailed visual inspection on the damaged component using more accurate inspection tool instead of visual inspection.

2. Conduct metallographic testing in order to obtain the mechanical properties of the material.

3. During tear down inspection, avoid removing metal particles around the inside face of the turbine body, the debris can be analyzed to detect any contaminant.

4. For history and background analysis, it's better to have longer period of historical background as the analysis on that part will be more extensive.

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