International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

Vol. 42 No. 2 January 2024, pp. 659-670

Analysis Of Reliability Pressure Regulated Valve Engine Rolls Royce Trent 700 On Airbus 330-300/200

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Abstract – Engine bleed valve or pressure regulated valve is one of the components in the engine bleed system which is located on the aircraft engine. This component is based on data removal of the pressure regulated valve component from PT. XYZ. Research using the fishbone diagram method and Why analysis is used to find the causes of frequent damage to PRV components. Then the Weibull distribution method is used to obtain the failure rate and reliability level of PRV components and determines the MTTF (Mean Time to Failure) value used to determine the schedule effective treatment. After evaluating the reliability using the Weibull method, the MTTF value of the pressure regulated valve was 9161.438 FH, the most common cause of PRV unshedule removal was not closed PRV which was caused by damage to several components such as butterfly valve corrosion, carbon actuator, spring, body actuator, piston, and piston guides.

Keywords – Pressure regulated valve (PRV); Fishbone diagram; 5 Why analysis; and Weibull.

I. Introduction

The Airbus 330-300/200 aircraft is a large capacity medium to long range wide body twin engine aircraft. This aircraft was developed from the Airbus A300, Airbus' first wide-body aircraft which was very successful on the market. This aircraft made its maiden flight on November 2, 1992 and was introduced to the market for the first time on January 17, 1994. In operation, this aircraft uses two General Electric CF6-80E, Pratt & Whitney PW4000 or Rolls Royce Trent 700 engines, all rated ETOPS-180. However, the majority of PT XYZ Airbus A330-300/200 aircraft use Rolls Royce Trent 700 engines [1]

In Indonesia, Aircraft is one of the modes of transportation that has high safety and security standards. Therefore, aircraft must meet the airworthiness standards listed in Law Number 1 of 2009 Chapter VIII Article 34 paragraph 1 which reads "Every aircraft operated must meet airworthiness standards". Airworthiness is the fulfillment of aircraft design type requirements so that it is safe to operate”[2]. To maintain airworthiness, according to Law Number 1 of 2009 article 46 paragraph 1 states that every person operating an aircraft is obliged to maintain the aircraft, aircraft engines, aircraft propellers, and their components to maintain reliability and airworthiness on an ongoing basis [3]. Maintenance activities have an important role in maintaining the operation of the aircraft system so that it remains as desired [4].

Reliability is needed to ensure that each component or part is in a serviceable state and runs according to function during aircraft operation [5]. Poor reliability of a component will greatly affect the smooth operation of the aircraft system. An example of the poor reliability of a component is the high frequency of component damage, this can cause obstacles to the smooth production process which results in not achieving production targets so that it can provide losses to the company [6].

One system that must always be maintained is the pneumatic system. The pneumatic system on the aircraft functions for various purposes such as opening and closing doors, engine starting, and brakes [7] (FAA, 2019). In addition, the pneumatic system on the aircraft is also used to maintain cabin pressure when the aircraft is at an altitude between 25,000 feet - 45,000 feet above sea level. At that altitude the available air pressure is only about 1.15 psi - 0.57 psi so that humans who are at that altitude are likely to experience disturbances due to feeling low air pressure, these disturbances include hypoxia, altitude sickness, and barotrauma [7].

The function of the pressure regulating valve is to control the air pressure coming from the IP or HP stage engine to obtain a permanently set downstream pressure at 3.03 to 3.59 barrels or 44 to 52 psig [1]. If there is damage to the component, it will affect the comfort and safety of passengers because this will make the pressure in the cabin unstable [8].

Based on research conducted by [9]. The most damage to the pressure regulated valve on the Airbus 320-200 aircraft is the PRV block in close and open position. This happens if there is damage to the BMC, sense line, control solenoid, XDCR bleed pressure regulator and the PRV itself. PRV damage occurs due to damage to the spring, packing, actuator cover, actuator ring, and shaft seal. Based on research by [14] entitled Analysis of the Airbus A330 Pneumatic Starter Using Reliability Methods to Prevent Performance Delays During Operation, it was found that damage to the pneumatic starter was caused by 3 damaged components, namely the turbine wheel, seal and bearing. The proposed improvement to the pneumatic starter maintenance method is in the form of predictive maintenance from the previous one, namely breakdown maintenance by carrying out an overhaul or removal of the pneumatic starter at 1150 flight cycles which is taken from the MTTF (Mean Time To Failure) value from the results of calculations using the reliability method.

From the technical delay report data for 2017-2022, it states that there were 7 delay events and 2 of them resulted in aircraft experiencing RTA (return to apron), namely in 2020 and 2021, which were caused by damage on the pressure regulated valve. In addition, based on PT. XYZ aircraft flight maintenance log book (AFML) data, there are 148 unscheduled removals occurring on the pressure regulated valve component on Airbus A330-300/200 Aircraft from 2017 to 2022. There is a need for corrective action because the damage that occurs is categorized as a repetitive problem with determine the level of reliability of the pressure regulated valve component and provide recommendations for effective types of maintenance so as to minimize the incidence of delay and unscheduled removal on the pressure regulated valve component.

II. RESEARCH METHOD

This research uses a quantitative method with the help of the Weibull distribution because the author's desired condition is to calculate and determine the reliability value of the pressure regulated valve component so that the MTTF value of the pressure regulated valve component is obtained. The Weibull distribution was chosen because it has the advantage of providing a fairly accurate failure analysis and failure forecast with a very small sample [10]. Then in determining the factors causing the failure of the pressure regulated valve component, the author uses a qualitative method, namely by using a Fishbone diagram and Why analysis. Fishbone diagram can identifying problems and determining the causes of the emergence of these problems. Apart from being used to identify problems and determine their causes, this fishbone diagram can also be used in the change process [15]. To get results using Why analysis and Fishbone, the author will conduct interviews with several engineers holding the type rating of Airbus 330 aircraft at PT. XYZ.

Weibull distribution is one of the most frequently used distribution methods in solving reliability problems. The Weibull distribution method can be used to find the rate of increase in damage or decrease in damage [11]. Weibull analysis is used in the aviation world and has become a standard in determining the life or lifetime of components on aircraft. This is because it can predict damage so that the component life can be calculated and can make maintenance plans and replacement of these components effectively [10] - [12] Weibull Parameters.

The object of this final project research is the pressure regulated valve on Airbus A330-300/200 owned by PT XYZ. Based on the aircraft flight maintenance log (AFML) the component was reported to have 148 unscheduled removals, 7 delay events were found and 2 of them resulted in the aircraft having to RTA. Referring to the CMM (Component Maintenance Manual) of the pressure regulated valve. Pressure regulated valve (PRV) is a butterfly type valve with a diameter of 4 inches. PRV works normally in the temperature range of -40 ° C to 205 ° C (-40 ° F to 401 ° F). under normal conditions PRV can receive air pressure of 11.3 barrels (164 psig) with an air temperature of 405 ° C and the minimum pressure to open this valve is 8 psig [13]. This valve will automatically close if the following occurs:

1. There is an excess temperature towards the precooler exchanger which is 257 ° C ± 3 ° C (60 seconds delay).
2. There is excess pressure to the PRV which is 57 psig ± 3 psig (15 seconds delay).

3. Excess heat occurred in the pylon/wing/area around the fuselage flow.
4. APU bleed valve is not closed.
5. Starter valve is not closed.
6. Engine fire pushbutton switch.
7. Engine bleed push button switch.

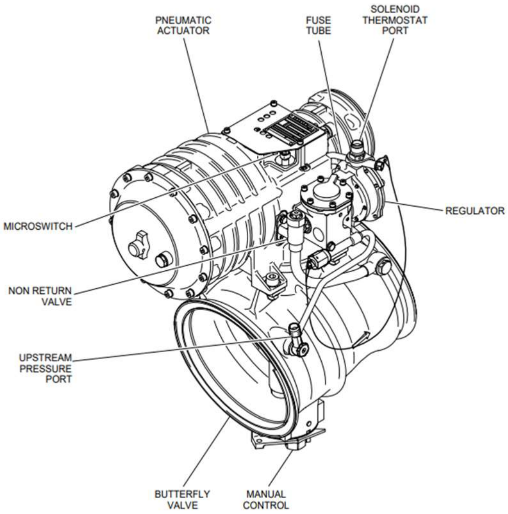

Fig 1. Pressure Regulated Valve (PRV)

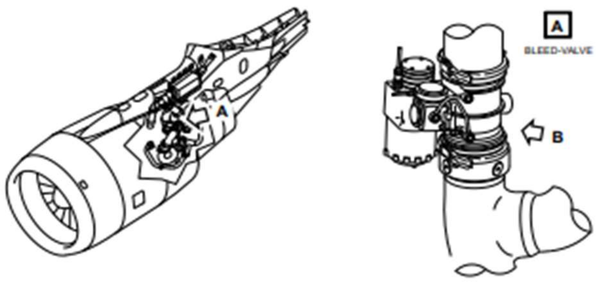

Fig 2. Location of Pressure Regulated Valve Pada Engine on Engine Roll Royce Trent 700

III. Result And Discussion

1. Quantitative Analysis

Quantitative analysis in this study was carried out by calculating the component reliability value based on aircraft flight maintenance log pressure regulated valve data on Airbus A330-300/200 aircraft taken from 2017 to 2022. Then from the data, the length of time the pressure regulated valve operates in units of flight hours is taken. Quantitative calculations are carried out by determining the value of the weibull distribution parameters first to determine the value of the component MTTF and its reliability value. in determining the value of the weibull distribution parameters, you can use Microsoft Excel by calculating the flight hour value of the component so that the weibull parameter value is obtained as follows:

Table 1 Weibull Parameter Value

No	Paramater	Value
1.	Shape Parameter (β)	0.925891014
2.	Scale Parameter (η)	8838.621759

After obtaining the values of η and β in Table 1, next is to find the MTTF, failure rate, reliability, and unreliability values of the components by entering the value of each parameter into the formulas below.

a. Determine the reliability value

To determine the reliability value, use the formula below so that the following value is obtained,

t = 0

$R(t) = e^{(-\frac{t}{\eta})^{\beta}}$

$R(t) = 2.718281828^{-(\frac{0}{8838.621759})^{0.925891014}}$

R(t) = 1 x 100%

R(t) = 100 %

t = 1000

$R(t) = e^{(-\frac{t}{\eta})^{\beta}}$

$R(t) = 2.718281828^{-(\frac{1000}{8838.621759})^{0.925891014}}$

R(t) = 0.875492061x 100%

R(t) = 87.55 %

b. Determine the unreliability value

To determine the unreliability value, use the formula below so that the following value is obtained,

t = 0

$F(t) = 1 - e^{-(\frac{t}{\eta})^{\beta}}$

$F(t) = 1- 2.718281828^{-(\frac{0}{8838.621759})^{0.925891014}}$

F(t) = 1-1

F(t) = 0

t = 1000 FH

$F(t) = 1 - e^{-(\frac{t}{\eta})^{\beta}}$

$F(t) = 1- 2.718281828^{-(\frac{1000}{8838.621759})^{0.925891014}}$

F(t) = 0.124507939 x 100%

F(t) = 12.45 %

c. Determine the failure rate value

To determine the failure rate value, use the formula below so that the following value is obtained,

t = 0

$\lambda\ (t) = \frac{f\,(t)}{R\ (t)} = \frac{\beta}{\eta}\ (\frac{t}{\eta})^{\beta-1}$

$\lambda(t) = (\frac{0.925891014}{8838.621759})(\frac{0}{8838.621759})^{0.925891014-}$

$\lambda(t) = 0$

t = 1000

failure rate value from t = 1000 FH is

$\lambda\ (t) = \frac{f\,(t)}{R\ (t)} = \frac{\beta}{\eta}\ (\frac{t}{\eta})^{\beta-1}$

$\lambda(t) = (\frac{0.925891014}{8838.621759})(\frac{1000}{8838.621759})^{0.925891014-}$

$\lambda(t) = 0.000123115$

Table 2 Reliability, Unreliability, and Failure Rate Valuae Interval 1000 FH

Time	Reliability (%)	Unreliability (%)	Failure Rate
0	100.00	0	0
1000	87.55	12.45079	0.000123115
2000	77.68	22.32389	0.00011695
3000	69.23	30.76867	0.000113489
4000	61.88	38.11836	0.000111095
5000	55.43	44.57247	0.000109273
6000	49.73	50.27236	0.000107806
7000	44.67	55.32633	0.000106581
8000	40.18	59.82118	0.000105532
9000	36.17	63.82832	0.000104615
10000	32.59	67.4077	0.000103801
11000	29.39	70.61023	0.00010307
12000	26.52	73.47965	0.000102408
13000	23.95	76.05375	0.000101802
14000	21.63	78.36544	0.000101245
15000	19.56	80.44349	0.000100728

Time	Reliability (%)	Unreliability (%)	Failure Rate
16000	17.69	82.31312	0.000100248
17000	16.00	83.99658	0.000099798
18000	14.49	85.5135	0.000099377
19000	13.12	86.88127	0.000098979
20000	11.88	88.1153	0.000098604

a. Determine the MTTF Value

The MTTF value of the PRV component can be found by using the MTTF formula below so that the following value is obtained,

MTTF = 8838.621759 $\Gamma(1 + \frac{1}{0.925891014})$

MTTF = 8838.621759 x 1.036523307

MTTF = 9161.437696 FH

From the calculation of the MTTF value, the MTTF value of the PRV component is 9161.437696 FH. This value will be used as a reference to determine a more effective PRV component maintenance schedule.

e. PRV Component Flight Hour Relationship Graph to Failure Rate

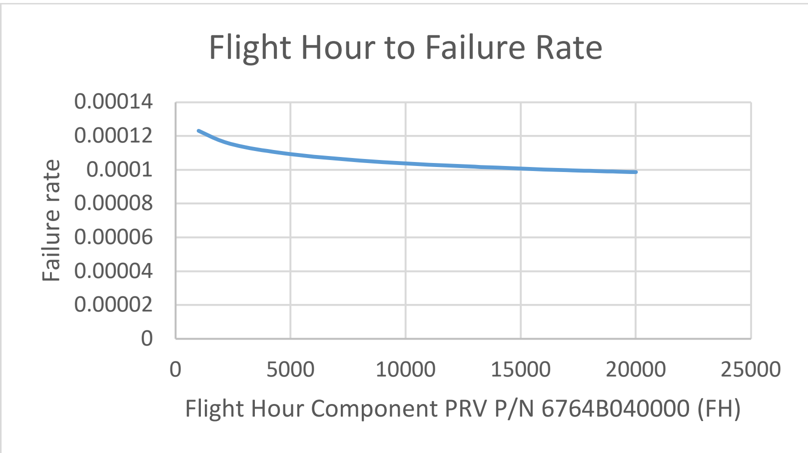

Fig 3. PRV Component Flight Hour Relationship Graph to Failure Rate

Based on the graph in Figure 3 the failure rate of the PRV component against the flight hour has decreased. This is because when the beta parameter is obtained smaller than 1, it will experience the Lindy Effect, according to Goldman the component will experience "childhood" where the failure rate will decrease according to the age of the component following the "Bathub Curve".

f. Relationship Graph of Reliability Value against Flight Hours

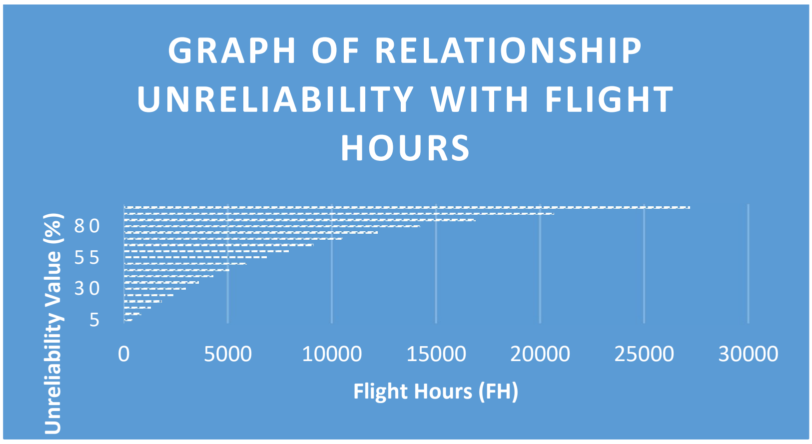

Fig 4.Relationship Graph of Reliability Value against Flight Hours

The inspection interval in the Maintenance Program (MP) of Airbus A330-300/200 is carried out every 20,000 FH. From the unreliability graph in Figure 4 shows that 88% of PRV failures occur before reaching the age of 20,000 FH (inspection interval from MP). This proves that there is still a high probability of PRV failure if inspections are still carried out at intervals of 20,000 FH. If the inspection interval is carried out lower than 20,000 FH in this case the author determines 9,000 FH (rounding results of MTTF calculations) then the possibility of PRV failure drops to 67%, which means it will increase the durability or reliability of PRV by 21%. From this graph, the author will propose a revision of the PRV Maintenance Program with MP Item Number 3611537201 in Appendix G from 20,000 FH to 9000 FH.

2. Qualitative Analysis

a. Determination of the dominant cause of Unscheduled Removal by Using Pareto Diagram

The number of unscheduled removal events on the pressure regulated valve component on Airbus A330-300 / 200, the determination of the dominant event is the reason for the unscheduled removal of the PRV component. The dominant event data will later be used to determine the reasons for causing component damage so that a solution to the problem is obtained. The following are the results of the pareto diagram of the causes of unscheduled removal of PRV components.

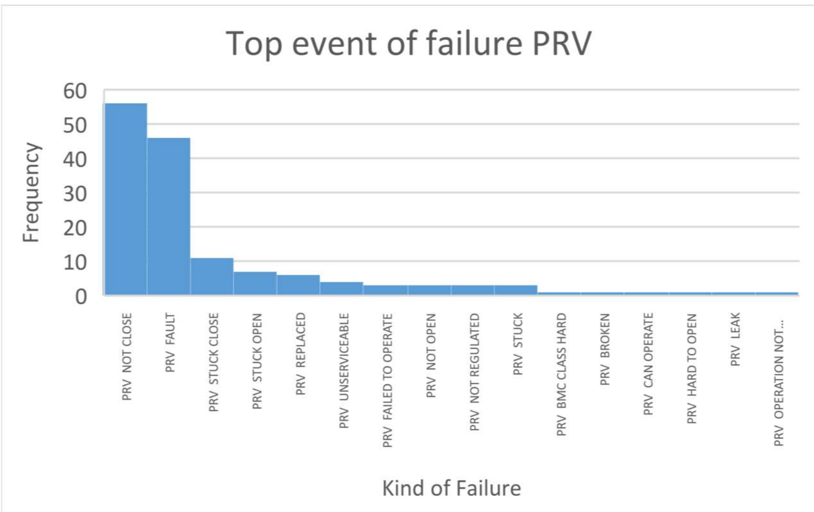

Fig 5. Pareto Cause of Unschedule Removal PRV

Causes of unscheduled maintenance of PRV components can be concluded that Pressure Regulated Valve not close is the reason for the highest cause of unscheduled maintenance on PRV with 56 or 39% of 148 unscheduled removals in 2017 to 2022. This data is obtained by the author based on the grouping of the amount of damage to the unschedule removal obtained on the AFML PRV Aircraft Airbus A330-300/200.

b. Determination of Cause of Failure Using Why Analysis

From the Pareto diagram of the failure, the root cause of the problem is sought using 5 why analysis. To obtain the data required in this method, the author conducted a series of discussions and interviews with the technician holder of the type rating of the Airbus A330 aircraft so that the following results were obtained.

No	*Why*	Cause	Corrective	Note
1.	Why does the pressure-regulated valve not close?	Because of maintenance issues, tools, people, and materials	1. Educate junior technicians on PRV handling procedures such as proper handling of calibrated training tools. 2. Held briefings by leaders and supervisors before carrying out activities. 3. Acculturating Take 2 before action (2 minutes before action to mitigate errors that occur). 4. Briefing by Quality personnel in charge before the installation of PRV related to QAR (Quality Assurance Reminder)	Results of interviews and brainstorming with Airbus A330 type rating engineers
2.	Why is there a problem with the maintenance process?	Due to lack of awareness such as knowledge and labor skills in installing and conditioning PRVs during maintenance.		
3.	Why is lack of labor awareness a problem during PRV maintenance?	Technicians who lack knowledge in performing maintenance on PRVs can cause more severe damage. For example: During C-Check, D-Check, and Overhaul maintenance that takes a long time, PRVs that have just been removed from the engine and placed in a designated storage area. Often it is not given a cover to protect the PRV from air humidity which has the potential to cause corrosion.		
3.	Why is installation a problem during maintenance?	Imperfect installation resulting in union defects due to the installation. The ideal installation is carried out by 3 personnel, 2 people holding while 1 person is a performer.		
4.	Why are tools a problem for Pressure-regulated valve damage?	Pressure-regulated valve maintenance uses several tools, namely bleed test set tools, nitrogen, and universal test ports. All tools are well calibrated but several tools are damaged, for example, bleed set tools that are damaged in the nipple section. In addition, there is a scarcity of tools	1. Keep each tool properly calibrated. 2. Require tools to always be checked, such as the suitability	Results of interviews and brainstorming with Airbus A330 type rating engineers

		available at the company.	of the nitrogen pressure indicator dial designation and the condition of the nipple on the bleed test set tools before use.	
5.	Why is the scarcity of tools one of the obstacles to PRV maintenance?	Because the company only provides 1 bleed set of tools. This disrupts the PRV maintenance process especially if the tools are needed by two different aircraft at the same time.		
6.	Why is material a problem for the pressure-regulated valve not closing?	Because some PRV components such as butterfly valves experience corrosion, and damage to the carbon actuator, spring, actuator body, piston, and guide piston.	1. Properly conditioning the storage area, namely good humidity control and covering the PRV that is detached from the engine. 2. Periodic checks are carried out in accordance with the Bleed valve check procedure AMM 36-11-00-720-816-A.	Results of interviews and brainstorming with Airbus A330 type rating engineers *Shop report* PRV
7.	Why is corrosion of the butterfly valve the problem of the pressure-regulated valve not closing?	Because corrosion restrains the butterfly's movement to open and close the valve normally with a predetermined pressure, the solenoid that makes it close is inhibited by corrosion so that it cannot move.		

c. Cause of Failure Analysis Using Fishbone Diagram

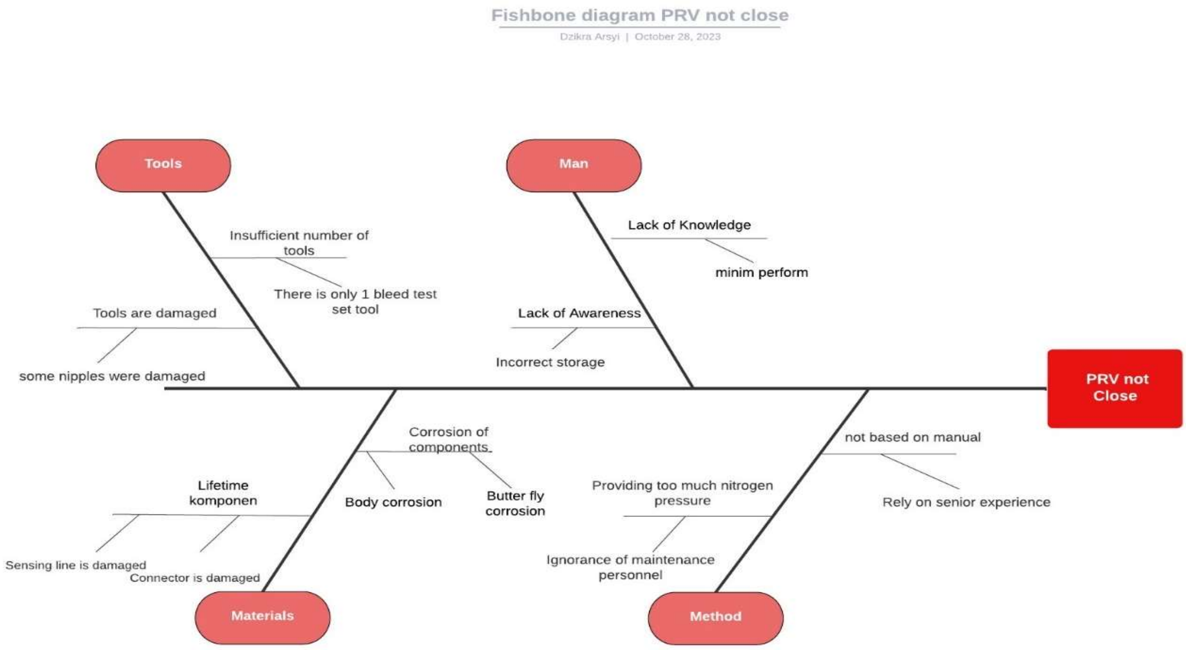

Fig 6. Fishbone Diagram of Causes PRV Fail

From the research data that has been obtained, there are several main causes of damage resulting in frequent PRV not closing during operation :

1) Man

Man is a factor related to humans, in this case, technicians or humans related to PRV maintenance. Personnel who lack experience in performing maintenance on PRVs from removing, installing, and troubleshooting damage to PRVs have the potential to cause more severe damage. In addition, the lack of awareness of personnel in handling PRV storage such as not providing covers can result in corrosion of PRV materials.

2) Materials

Materials are factors from within the PRV such as component lifetime and conditions when operating components at high temperatures and pressures continuously coupled with vibrations from the engine cause damage to several subcomponents such as butterfly valves experiencing corrosion, and damage to carbon actuators, springs, actuator bodies, pistons, guide pistons.

Fig 7. Actuator internal corrosion

Fig 8. Actuator piston blistered

Fig 9. Kinematic corroded

Fig 10. Actuator S/A - Actuator internal corrosion

3) Methods

Methods are factors that cause PRV damage caused by the wrong method during PRV maintenance, such as inspection errors that are not based on the manual, only following seniors who often carry out these maintenance activities, then excessive application of nitrogen pressure during maintenance which should follow the aircraft maintenance manual procedures.

4) Tools

Is a tool used for the maintenance of pressure-regulated valve components. There are various tools used for PRV maintenance such as bleed test set tools and nitrogen. The tools are already in a calibrated state but there are several parts of the tools that are damaged such as missing and damaged nipples. In addition, in the company, the availability of bleed test set tools is very minimal, which is only available 1 so technicians have difficulty if there is more than one PRV that requires maintenance.

IV. Conclusion

The results of the reliability calculation of the PRV component using the Weibull distribution, the MTTF (Mean Time to Failure) value of the PRV component is 9161.437696 FH, meaning that the average value of PRV failure occurs at the flight hour. In addition, the reliability level value of the PRV is 35.66% at flight hours 9161.437696. The results of the search for the cause of failure of the PRV Not Close/Stuck Open damage type problem using the Whys analysis method and fishbone diagram as the following results were obtained:

1. PRV Not Close/Stuck Open is caused by several factors, namely human factors, materials, and tools used for maintenance.

2. Damage to the human factor is the cause of PRV Not Close/Stuck Open due to the lack of concern of some technicians in treating PRV components that have just been removed which should be wrapped to prevent air humidity contamination which can cause corrosion. In addition, the use of inappropriate tools, namely stick ¾ when the PRV is not close occurs and lack of experience in installation can cause damage to the PRV.
3. Damage to the material causes PRV Not to Close/Stuck Open because there is corrosion of several PRV subcomponents such as the actuator body, butterfly valve, connector, shaft valve carbon actuator, spring, piston, and guide piston. This affects the function of opening and closing the valve which is hampered due to corrosion.
4. Damage to tools is the cause of PRV Not Close / Stuck Open because the bleed set test tools used for healthy checks, although calibrated, have several nipples on the bleed set test tools that are damaged and the availability of bleed set test tools in the company is limited.

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