UNSYS digital

The Journal of Instrumentation, Automation and Systems

Design of Vacuum Test Machine for Modulator and Telescope Turbine

Febryan Maulana

BPPT, Kawasan PUSPIPTEK, Setu, Serpong, Tangerang Selatan, Banten, Indonesia

Abstract— While assembling modulator with telescope turbine, a vacuum process as a final stage of the tools maintenance is required. The goal is to remove trapped air and replace it entirely with oil. Therefore, it requires a vacuum machine that can help the process. The existing machine takes quite a long process of up to 3.5 - 4.5 hours. The other side the existing machine cannot be moved (fixed). The air flow and the incoming oil just rely on one valve, so it needs a tool to speed up the processing time that will be a benchmark and productivity growth. The design process is also made in order to ease the operation and easy movement by totally changing the existing design with the new one. The design starts from the idea of using two valves from the originally one valve, change of operational system, as well as the capacity of the charging tube (oil buck), which will be relatively larger. The vacuum test machine using two valves is expected to overcome the existing problem, to ease operation and to improve efficiency.

Keywords—Vacuum test, modulator, Telescope Turbine.

Copyright © 2016. Published by UNSYSdigital. All rights reserved.

DOI: 10.21535/4s7ktd63

I. Introduction

A service company engages in the drilling service or as a contractor of oil and gas company specializing in the provision of drilling tools. This company has a variety of equipment, which are divided into several divisions: MWD (Measurement While Drilling), LWD (Logging While Drilling), Motor / Power Drive also Surface. These divisions are separated because each has a role in the process of drilling an oil well. Especially for MWD there are tools that need to be maintained regularly, and for each drilling completion cycle. Tools usage involves rotating components that requires lubricating oil, which is in pressurized condition. As a medium of endurance and strength in the drilling process, the pressure inside the tools is greater than the pressure outside (pressure of environment during drilling oil well). In this process each tool has characteristics and endurance for use of drilling: 0-100 hours, >100 hours, >250 hours, >750 hours.

Therefore the tools which are maintained step by step (maintenance service level) periodically is overhauled based on the calculation of work hour of the tools themselves so that each of the tools needs to change and oil refilled after treatment (replaced spare parts) in advance. One example of tools that needs vacuum process at MWD Tools is telescope which consists of turbine and modulator.

Vacuum machine is required in the process of air exchange with fluid (oil), or the process of sucking air trapped in the tools optimally to be replaced with a fluid (oil). Vacuum machine is a combination between rotary vane pump with other components assembled in a system.

Rotary Vane Pump is one type of pump that is included in the category of positive displacement pumps (reciprocating positive displacement pump) where the rotor vane pump is in the form of a cylinder rotor wrapped in a casing which has the same formations. Function of motor is to suck substance between the rotor and the casing. The vacuum test is to suck the remaining air. Mechanism of vane rotary pump is similar to a scroll compressor.

The rotary vane pump is becoming an important part of the unit of vacuum machine, because the machine has a primary function as a power soaking in which the pump determines magnitude of air suction power in tools, so that any trapped air drawn out and the whole air is replaced with oil.

The suction process resulted from rotary vane pump is utilized in the process of vacuum to suck air in tools (modulator and turbine), and replace it with oil. The process of vacuum test takes between 3.5-4.5 hours. As the time for turbine service is limited, a solution to speed up the existing process time is needed.

A vacuum machine is a machine consisting of centrifugal pump machine which is assembled with components of vacuum-like air tube oil container (chamber) and hose which is connected to the connector (valve) to the tools to pull air from the inside then replace it with oil. In this process, air in the vacuum machine assembly is replaced by oil entirely and without residual air that may be trapped inside. Because oil plays an important role as a lubrication media in parts of revolving tools as well as durability media of tools which are shaped and designed as a pressure compensator whose function is to withstand a pressure difference between outside oil wells and the oil pressure in the tools that are drilling, ideally the pressure in the tool is greater (P pressure compensator> P environment) or at least equal to the pressure outside the well (P pressure compensator = P environment) in order to avoid the

Corresponding author: F. Maulana (e-mail: febryan.maulana86@gmail.com).

This paper was submitted on March 15, 2016; revised on August 16, 2016; and accepted on August 16, 2016.

entry of mud that will damage the components of tools in it (mud invaded). Some of the problem formulations raised is the necessity to redesign the test vacuum machine of turbine and modulator. The followings are formulations of the problem that arise so that a solution is required in order to ease its use:

1. Demand of a vacuum machine with shorter processing time to increase time of productivity and also efficiency of process time especially vacuum test.
2. Demand of a machine that can produce a maximum vacuum ability shown by the elimination of air trapped inside to be replaced with oil entirely. Demand of the design of the vacuum machine.
3. Demand of the larger engine capacity and oil volume that is accommodated to compress into tools to ease the release of exchange of air with oil faster, in the process of vacuum test of turbine and modulators.

II. THEORY

The pump can be classified (**Figure 1**) based on the usefulness, the material of the pumps, and also on liquids or gases streamed. But in principle the work of pump is divided into two types; dynamic pumps and positive displacement pump [5].

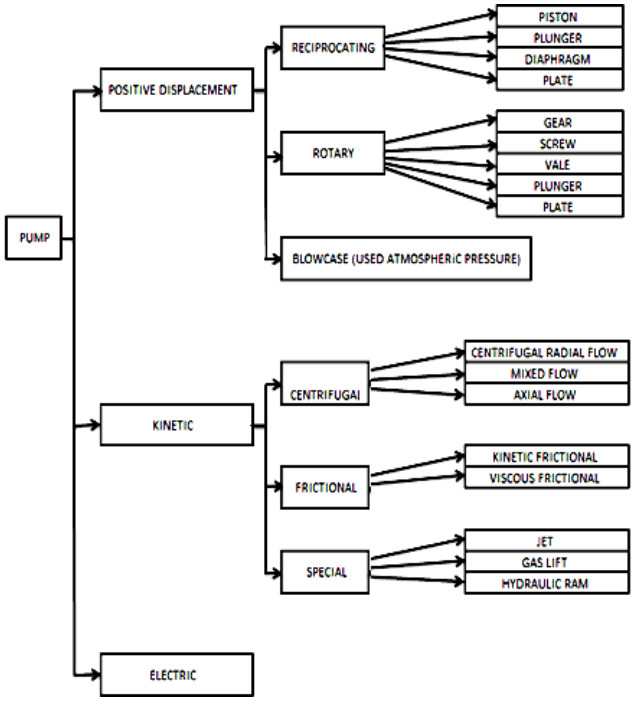


Figure 1 Pumps Classification (Shin Nippon Machinery Co.,Ltd)

The working principle of dynamic pump is to increase the amount of pressure using the rotation of the impeller to increase the rate of flow speed. In this type of pump, the liquid mechanical energy is enhanced by centrifugal action. Pump is installed to provide energy to withdraw liquid from the source and make it flow with a constant volumetric flow rate when it goes out at a certain height above the pump. At the pump liquid enters through a suction connection and out through an exhaust connection.

A positive displacement pump increases the amount of pressure using a fixed amount of fluid volume in a limited space. In this type of pump, a certain volume of liquid trapped inside a room which alternately filled through the entry and emptied at a higher pressure through the exhaust. In the reciprocating pump the space is a stationary cylinder containing a piston or plunger. In rotary pump the space moves from entry to exhaust and go back into the inlet.

Pump capacity is expressed in m^3/h either for liquid or gaseous fluid. In U.S. unit system capacity is expressed in gallon/min for liquid and ft^3/min for gas [4]. Capacity in units of volume can be converted into mass units by using density or specific gravity. If the drained fluid is gas, capacity must be expressed with respect to the inlet temperature or pressure.

The vacuum pump is a device that move or flow fluids. The vacuum pump was invented in 1650 by Otto von Guericke.

The vacuum pump is widely used in:

1. Plastic molding process (VRTM)
2. Driving some flight instrument in aircraft
3. Production of most types of electric lamps, vacuum tubes, and CRTs where the device is rechargeable with a particular gas or gas mixture
4. Vacuum Coating for decoration, for endurance, for saving energy, etc.

One example of a pump that is used in this application is a rotary vane pump.

A. Rotary Vane Pump and work principle of Rotary Vane Pump

Rotary Vane Pump is one type of pump that is included in the category of reciprocating positive displacement pump. In the principle of pumps and the mechanism of work of this vacuum test the fluid is in the form of air pull by the pump. Mechanism of rotary vane pump is similar to a scroll compressor.

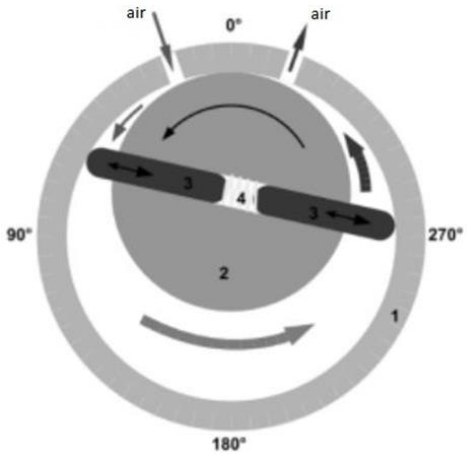


Figure 2 Rotary Vane Pump principle [10]

Vane pump can handle moderate viscosity liquids, which excels in handling low viscosity liquids such as LP gas (propane), ammonia, solvents, alcohol, fuel oil, gasoline, and refrigerants. Vane pump does not have metal contact to internal and self-metal to compensate its use, enable them to maintain maximum performance of non-lubricating fluid. Although the efficiency decreases rapidly, they can be used up to 500 cPs/2,300 SSU.

Vane pump have same work mechanism, though different configurations.

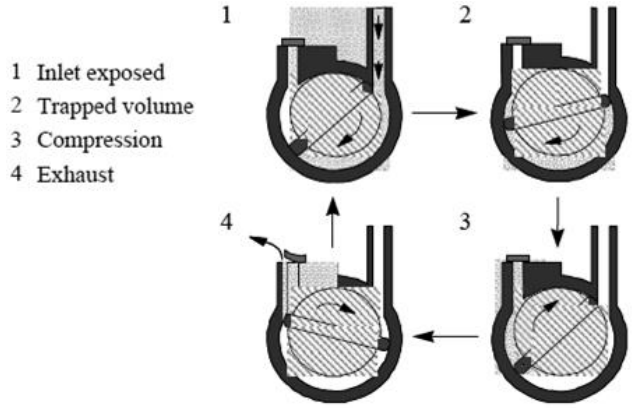


Figure 1 Working Mechanism of Vacuum Machine [10]

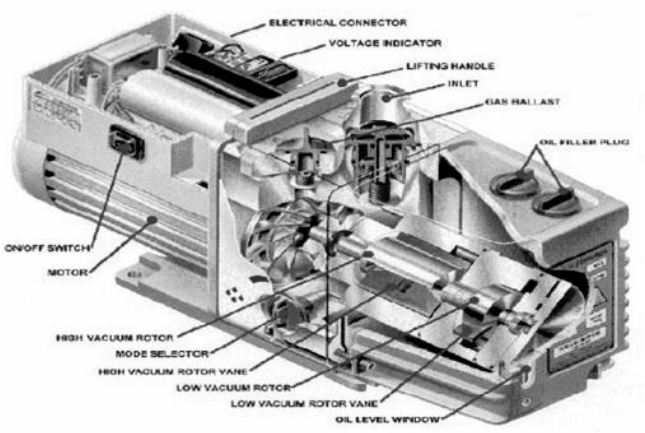


Figure 2 Pictures of parts and components of vacuum (EDWARD RV5)

B. Electric Motor

In principle, the vacuum pump works by suction method with vacuum pressure (<1 atm). The observed vacuum pump, is a type of vacuum pump that is often called a kinetic pump. The vacuum pump works by streaming and pushing gas or in such manner that the gas is pushed out of the inlet pump to the outlet pump. Air from outside is sucked in by an electric motor and deliver it into the vacuum tube [11]. Inside the vacuum tube, the air is vacuumed so that air pressure becomes very low. Then the air goes into the main unit. Inside this main unit the air goes into the inlet pump to the outlet pump.

The moving valve in the pump accelerates the rate of gas molecules and makes the area inside the pump low-pressurized. Furthermore, the tank is isolated using the vacuum valve. If this valve stops, each gas exchange occurs between the container and the pump

Then the gas enters the filter tube. Inside the filter tube, gas is filtered to avoid any oil or water that is carried by the gas to the output pump.

The vacuum pump consists of a main unit which is divided into three parts: a vacuum tube, filtration tube (consisting of filtration tube and filter rubber) and electric motor (consisting of a mover motor, the rotor, stator and insulation).

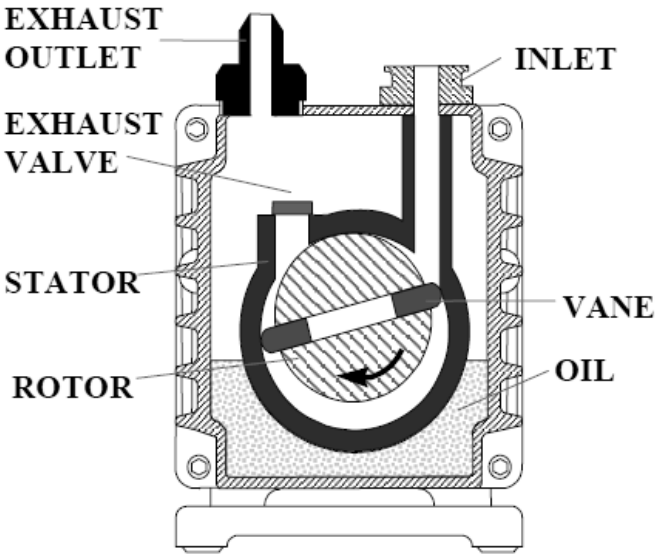


Figure 3 Scheme and an image of the vacuum pump [10]

C. Oil (fluid media)

Fluid is a substance that cannot withstand deformation (distortion) permanently. When it will try to change the form of a fluid mass, then in the fluid layers would emerge in which one layer will flow over the other layers in order to reach a new form. During the change of the form, there is the shear stress with the amount that depends on the viscosity of the fluid and the relative fluid flow rate to the certain direction. When the fluid gets to its final form, the shear stress will disappear so that the fluid is in a state of equilibrium.

D. Viscosity Oil

Viscosity (η) is related to the magnitude of the frictional force between layers of the liquid substance, and also between the liquid with the pipe wall. For liquid fluid flowing in the pipe, the type of flow can be laminar flow or turbulent flow. Both types of flow are related to the value η, density (ρ), the flow velocity (v) the liquid, and the pipe diameter (D) in which the fluid flows. The relation is stated in the Reynolds number (Re):

$$R_e = \frac{\rho v D}{\eta} \qquad \textbf{(1)}$$

When Re is small (< 2000), the liquid flow is laminar (each part of liquid flow follows its own current line, and the current lines never intersect with each other). Conversely, when Re is big (> 4000), the fluid flows turbulently (occurring eddy currents). Equation **(1)** shows that Re is small when η is big

means, the existence of η which is greater makes flow tend laminar.

When the fluid flow is laminar then controlled by the Poiseuille equation. If the liquid flows in the pipeline with length l radius R, the viscosity (thickness) η, on debit Q then the equation of Poiseuille is stated:

$$Q = \frac{\pi R^4 \Delta P}{8 \eta l} \quad \textbf{(2)}$$

Referring to equation **(2)**, on the same R, l, and ΔP then Q becomes small when η is big. That is because Q is proportional to the flow velocity of liquids (v) on the fixed R. It means that η is inversely proportional to v. This formulation is used as the basis of Ostwald viscometer that is the measurement of η based on the flow velocity of liquid.

E. Pressure on Fluid

The pressure caused by stationary liquid at a specific depth is called hydrostatic pressure. The amount of hydrostatic pressure depends on all heights of liquid, the density of the liquid, and the acceleration of gravity [5]. To calculate the pressure of the liquid substance the following equation can be used:

$$P = \rho . g . h \quad \textbf{(3)}$$

where P, ρ, h, and g are pressure (N/m^2), density (kg/m^3), depth (m), gravity acceleration (m/s^2), respectively.

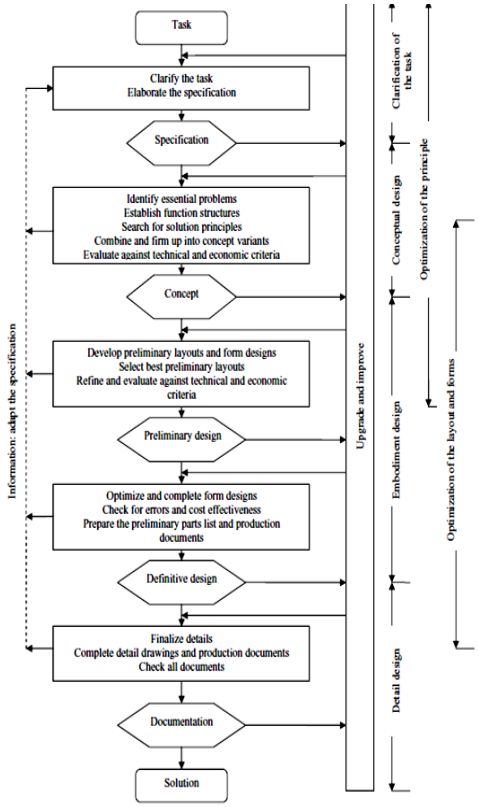


Figure 6 Flowchart Pahl dan Beitz Method [6]

F. Methods of making engineering design

Designing the means and analyzing idea are carried out to solve the problem [1]. A certain method is to be used to realize the idea is to produce a scientific real work and responsibility.

1) Pahl and Beitz Method

This is a systematic design approach for the evaluation concept which is developed in Germany, and the method of evolution based on the use of analysis value [6]. All designs of product are divided into design for separate functional modules.

Each module can be considered independently with the interactions between them are being kept to a minimum.

2) VDI Method

By using the work steps contained in VDI 2221[3], several variants of product are analyzed, and then the best combination is selected, to evaluate it by determining the overall value of the variants concept.

G. Pro/ENGINEER

Pro/ENGINEER is a design software based on 3-dimensional images (mass, volume and center of gravity).

Three-dimensional components with the properties (mass, volume, center of gravity) in 3-dimensional images can be directly used for software applications of CAE (Computer Aided Engineering) and CAM (Computer Aided Manufacturing). With CAE applications the behavior of a component can be seen when getting a force, load, heat treatment, etc.

III. Research Methodology

Good research results are determined by the research methodology that is arranged and structured well, therefore this section describes the steps of research done and methods used in analyzing changes in the design of vacuum test machine of turbine and modulator of telescope tools in the oil service company

A. Preliminary Study

1) Field study

This research was conducted in the oil service company when the process of drawing air on tools of turbine and modulator that took 4 to 6 hours per tools. This motivated the researcher to conduct innovation of design changes to speed up the process of vacuum test to increase its efficiency.

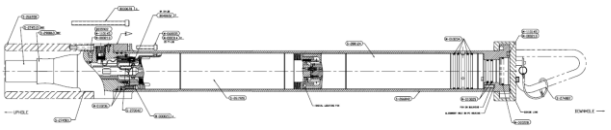


Figure 7 Modulator

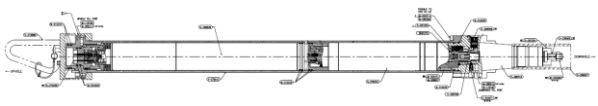


Figure 8 Turbine

2) Literature

The literature study was done by reading books, journals, and other reference sources related to maintenance and reliability and theoretical manufacture design as well as the relevant data supporting the process of problem-solving and analysis as well as alternatives.

B. Main Problem

The activities using machine of vacuum test is very routinely used in the process of regular maintenance. But the constraints often occur within the processing time of 4 to 6 hours per tools, so it takes a long time to replace oil (turbine oil Aerosheell 560)[7]. Based on the data of turbine and modulators maintenance the processing time required prior to vacuum test is 3 to 4 hours. A vacuum test takes less than 1 day (≤ 7 hours).

C. Data Collection

To get the data, multiple data collection techniques is used, among others:

1) Documentation Method

Retrieved data from vacuum activity over a short period in January to February 2012 are:

a. Time and frequency of vacuum test
b. Subsystems on engine vacuum.
c. Design retrieval method.

The following frequency data vacuum test with a time of maintenance (disassembly to assembly).

TABLE I CYCLE TIME VACUUM TEST (TURBINE AND MODULATOR)

No	Date	M10 Tools Assy		Maintenance Times		Vacuum Times	Total Time
		Modulator	Turbine	Dissasembly	Assembly		
1	1/1/2012	Modulator		2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
2	1/2/2012		Turbine	2 Hours	2 Hours	5 hours	9 Hrs
3	1/3/2012	Modulator		2 Hours	2 Hours	5 hours	9 Hrs
4	1/4/2012		Turbine	2 Hours	2 Hours	4 hours	8 Hrs
5	1/5/2012	Modulator		2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
6	1/6/2012		Turbine	2 Hours	2 Hours	5 hours	9 Hrs
9	1/9/2012	Modulator		2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
10	1/10/2012		Turbine	2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
11	1/11/2012	Modulator		2 Hours	2 Hours	4 hours	8 Hrs
12	1/12/2012		Turbine	2 Hours	2 Hours	5 hours	9 Hrs
13	1/13/2012	Modulator		2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
16	1/16/2012		Turbine	2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
17	1/17/2012	Modulator		2 Hours	2 Hours	4 hours	8 Hrs
18	1/18/2012		Turbine	2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
19	1/19/2012	Modulator		2 Hours	2 Hours	5 hours	9 Hrs
20	1/20/2012		Turbine	2 Hours	2 Hours	4 hours	8 Hrs
21	1/23/2012	Modulator		2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
22	1/24/2012		Turbine	2 Hours	2 Hours	5 hours	9 Hrs
23	1/25/2012	Modulator		2 Hours	2 Hours	4 hours	9 Hrs
24	1/26/2012		Turbine	2 Hours	2 Hours	4 Hours 30 min	8.5 Hrs
25	1/27/2012	Modulator		2 Hours	2 Hours	4 hours	8 Hrs
26	1/30/2012		Turbine	2 Hours	2 Hours	5 hours	9 Hrs

TABLE I shows the time of vacuum test is longer than the time of disassembly (maintenance time starting disassembly to assembly times), which should not be longer than the maintenance time.

The following is the operating system of vacuum test which was used in between January 2009 to March.

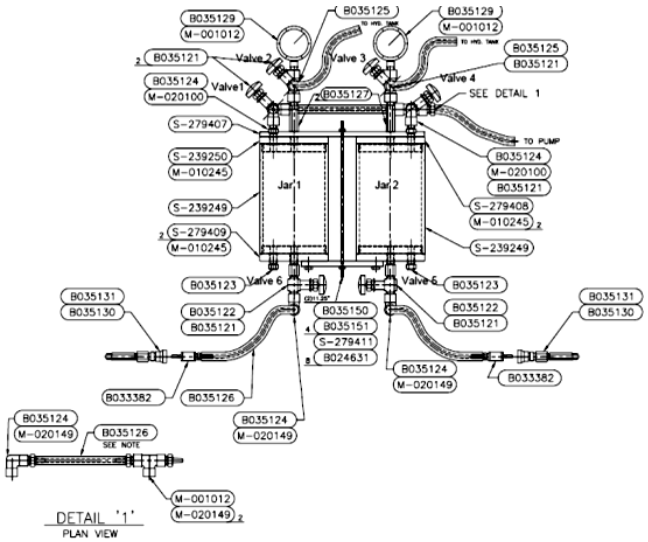


Figure 4 Engine vacuum existing test

Methods of taking design solutions used are methods of Pahl and Beitz with method of Interview (Brainstorming).

D. Processing and Data Analysis

1) Data Processing

In the reliability analysis, the rate of engine failure is determined by the concept of Pahl and Beitz (1964). The steps in processing the data are as follow:

a) Problem

Making changes either a new design or a modification of the old design with the purpose to get shorter time efficiency as well as changes in power and oil capacity in the chamber to speed up the processing time in the vacuum test [6]. Among them:

1. Changing the volume capacity of oil chamber as a medium for greater vacuum area
   a. Capacity
   b. The greater the pressure on the caused during the vacuum test.
2. Replace the power and capacity of the machine with a new model and brand.
3. Change the circulation flow between the vacuum test with filling after the vacuum process is easier to operate.
4. Replace the permanent/fixed engine function to be movable.

b) Specification

In the vacuum machine, its engine is set in the fixed area (fixed placement), the machine cannot be moved. With the results of the analysis and the field observation of vacuum test, engine is designed to be easily moved and to increase the suction power by larger chamber design using a new vacuum machine that is rotary vane.

c) Concept

By analyzing the existing obstacles and find some solutions so that the design of the machine will be made following the proposed changes, including:

1. New chamber design with a larger oil capacity volume
2. Larger machine power so as to accelerate the process pace.
3. Flow cycle of vacuum test speeds up the process and a complex scheme to separate the state of vacuum and transfer.

d) Preliminary design

In the initial design the concept of the oil displacement is only applied if the chamber (tube) of oil experiences a vacuum, then the valve of regulator is opened and closed in the release so that the air that has been trapped in the chamber goes out freely, and the oil in the chamber goes into the tools, the following is a process of initial mechanism of oil goes into the tools gradually.

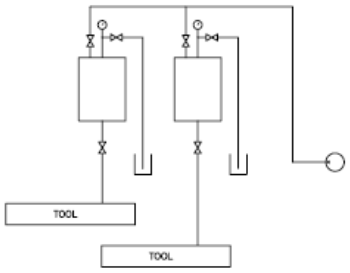
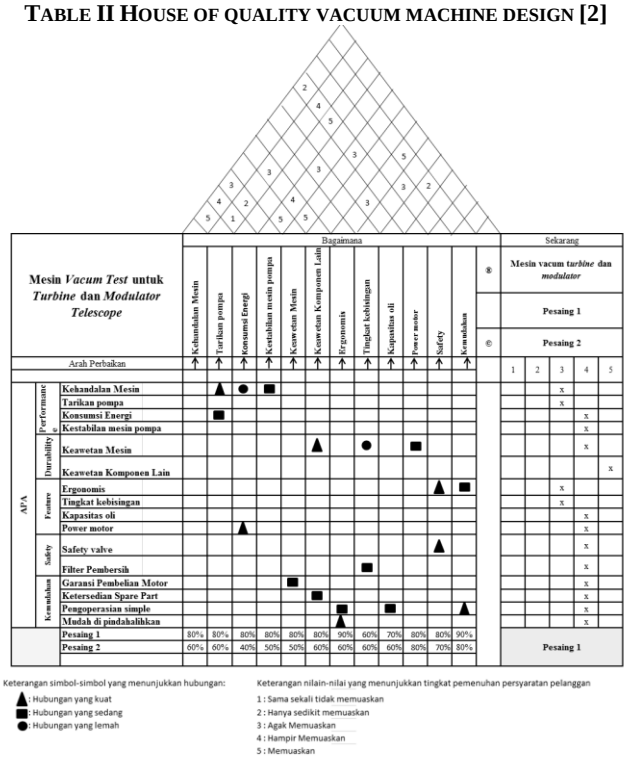


Figure 5 The working principle of vacuum machines current condition

TABLE II HOUSE OF QUALITY VACUUM MACHINE DESIGN [2]



The weaknesses of the initial design are:

1. The capacity of the small chamber.
2. Only relying on vacuum in one chamber and one valve.

Time of the process of vacuum + filling oil is quite long.

e) Determination of the latest design

With the designed vacuum test machine, there are two processes called:

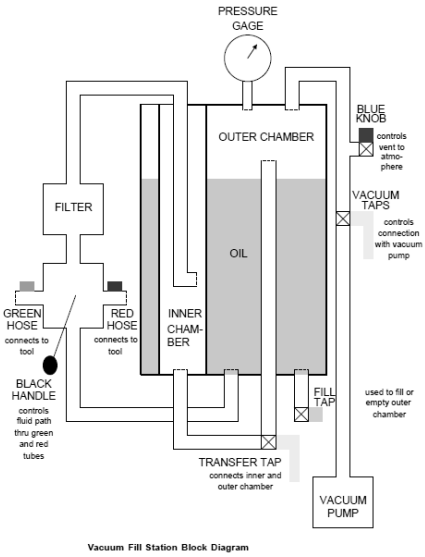


Figure 6 New Design of Vacuum Test

1. Drawing

That is the process of removing the air trapped and contaminated in the oil.

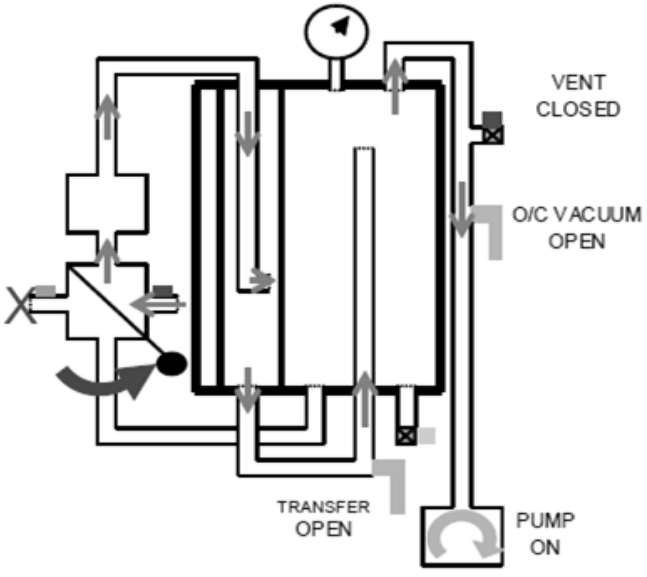


Figure 7 Drawing Process

2. Transfer

That is the process of moving oil (aerosheell turbine oil 560) from the outer chamber into tools while taking air into the inner chamber

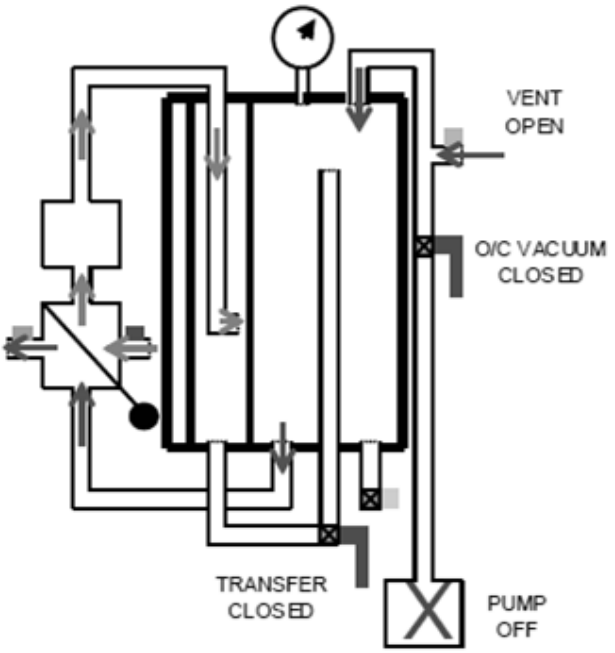


Figure 8 Transfer Process

f) Collection of document

The collection of data and documents related to a design.

g) Solution

The design tools for more efficient performance than previous one.

IV. Detail of Design

A. Calculation of processing time of vacuum test machine

In the discussion of following calculation explains that there are several counts related to the process of vacuum that will be designed, the following is the picture.

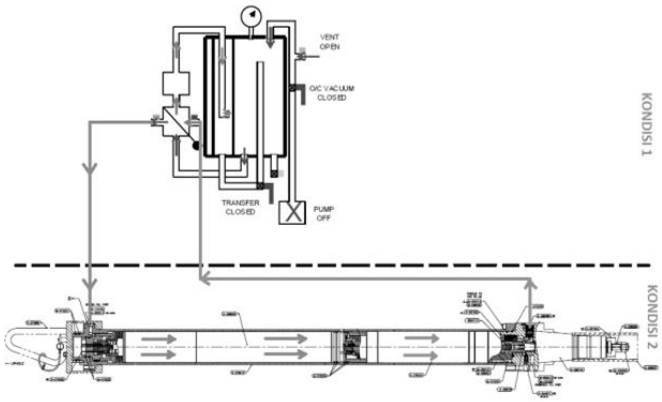


Figure 9 Analysis Calculation of conditions 1 and 2

Resistance values will affect how long the oil flow in the vacuum process. In this case, the factors include: flow velocity, flow sectional width, friction factor, viscosity, and fluid density. Also the losses contained in the fluid flow include:

1. Pressure drop
2. Head loss

Here are the results of measurements after realization was made.

Table III Data comparison of measurements from new and old engines

Equipment	1	2	3	4	5	6	7	8	Remark
Turbine	4.5 Hrs	5.0 Hrs	4.5 Hrs	5.0 Hrs	4.0 Hrs	5.0 Hrs	4.5 Hrs	4.0 Hrs	Old Vacuum
Turbine	1.5 Hrs	2.0 Hrs	2.0 Hrs	2.0 Hrs	1.5 Hrs	2.0 Hrs	1.5 Hrs	2.0 Hrs	New Vacuum
Modulator	4.0 Hrs	4.0 Hrs	4.5 Hrs	4.0 Hrs	4.0 Hrs	4.0 Hrs	4.5 Hrs	4.0 Hrs	Old Vacuum
Modulator	1.5 Hrs	1.0 Hrs	1.5 Hrs	1.0 Hrs	1.0 Hrs	1.0 Hrs	1.5 Hrs	2.0 Hrs	New Vacuum

B. Manufacture and operational data from the result of field study

Table IV Result data for time process measurement of new vacuum test Machine

NO	Telelscope		Set Up time (Hrs)		*Vacuum Time*	*Total*	
	Turbine	Modulator	Assembly	Dissasembly			Hrs
1	Turbine		0.25	0.5	2	2.75	Hrs
		Modulator	0.3	0.5	1.5	2.3	Hrs
2	Turbine		0.3	0.4	1.5	2.2	Hrs
		Modulator	0.25	0.5	2	2.75	Hrs
3	Turbine		0.3	0.3	2	2.6	Hrs
		Modulator	0.25	0.3	1.5	2.05	Hrs
4	Turbine		0.3	0.4	2	2.7	Hrs
		Modulator	0.3	0.25	2	2.55	Hrs
5	Turbine		0.25	0.4	2	2.65	Hrs
		Modulator	0.25	0.4	1.5	2.15	Hrs
6	Turbine		0.25	0.4	2.5	3.15	Hrs
		Modulator	0.3	0.4	1.5	2.2	Hrs
7	Turbine		0.3	0.4	2	2.7	Hrs
		Modulator	0.25	0.4	2	2.65	Hrs
8	Turbine		0.3	0.3	1.5	2.1	Hrs
		Modulator	0.3	0.3	2	2.6	Hrs
9	Turbine		0.25	0.3	1.5	2.05	Hrs
		Modulator	0.25	0.5	1.5	2.25	Hrs
10	Turbine		0.25	0.5	2	2.75	Hrs
		Modulator	0.3	0.5	1.5	2.3	Hrs
11	Turbine		0.3	0.5	2	2.8	Hrs
		Modulator	0.3	0.4	1.5	2.2	Hrs
12	Turbine		0.2	0.4	2	2.6	Hrs
		Modulator	0.3	0.4	1.5	2.2	Hrs
13	Turbine		0.2	0.4	2	2.6	Hrs
		Modulator	0.3	0.3	1.5	2.1	Hrs

C. Calculation of construction and volume on the new vacuum machine

The purpose of the calculations is to know the technical specification that is used to determine the specification of plate and the magnitude of force needed to sustain the supported load.

1. Mass of aluminum top plate base (top / bottom base plate)
2. Mass of buffer plate base (cover plate)
3. Mass of inner small tube (inner oil buck)
4. Mass of big outer tube (outer oil buck)
5. Calculation of the load on the oil chamber 1
6. Calculation of the strength of the plate material

V. CONCLUSION

By designing a new vacuum test machine, the vacuum processes at the modulator and turbine M10 were improved. The achieved improvement includes:

1. The processing time is shorter from initially 4.5 hours to 1.5-2 hours.
2. The larger capacity of the charging tube (chamber), *i.e.*, 5.6637 x 10^{-3} m^3 or 56.637 liters.
3. Simple operation of the machine, and easier to switch in the use in accordance with the space provided.
4. Change of the oil flow diagram schematic in which air is replaced with oil in shorter time than drawing and transfer system.
5. Time to set up the installation of vacuum process is shorter.

REFERENCES

[1] Butterworth-Heinemann, Elsevier, Design Engineering Manual, First Edition, Burlington, MA 01803, USA

[2] Nigel Cross, 2005, Strategies for Product Design, Engineering Design Methods, Fourth Edition, The Open University, Milton Keynes, UK.

[3] Harsokoesoemo, H. Darmawan, 2004, Pengantar Perancangan Teknik, Penerbit ITB, Bandung.

[4] Potter, Le.C., D.C.Winggert, and Bassem H. Ramadhan, 2001, Mechanics of Fluide Fourth Editions,SI,USA

[5] Massey,Bernard Stanford and John Ward Smith, Mechanics of Fluids, Volume 1

[6] Pahl, G dan W. Beitz,1984, Engineering Design , The design Council, London

[7] http://www.shell.com/product/aeroshell560 (downloaded on 17 July 2012)

[8] http://www.dtic.mil/cgi-bin/GetTRDDoc Handbook for Design of Undersea, Pressure (downloaded on 2 August 2012)

[9] Tsokos, K.A., Standard and Higher Level, Phyiscs for the IB Diploma Fifth Edition. Cambridge University Press.

[10] www.edwardsvacuum.com/Products/76950/overview/Product_Details.aspx (downloaded on 30 January 2013)

[11] Dorf, Richard C., 2004, Press LLC,HandBook of Engineering Table, University of California, Davis, CRC