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Design and Development of Flow Loss Testing Device in Pipe Installation Using VDI 2221 Method

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Abstract-- *Piping installation is a medium for fluid transfer which has many design variations. The design used can affect the flow rate of the fluid. The effect comes from head losses which are divided into major losses and minor losses. Basically, major losses are losses caused by straight pipes while minor losses are losses due to pipe components. These components can be in the form of bends, connections, branching and changes in cross-sectional size. Losses that occur in pipe flow can be studied by direct simulation. To carry out a direct simulation, a test tool is needed that can help analyze losses that occur in fluid flow in pipe installations. The design that is carried out refers to the use of pipe installations that are often encountered including its components. The system design of the flow loss test equipment is selected using the VDI 2221 method. The selection of components is carried out by comparing the variations in the arrangement of system components. From the results of this comparison, the best variation was obtained with the results of the main PVC pipe, 108 bit Shimizu jet pump, ball valve type, pressure gauge capacity of 2.5 bar, flowmeter capacity of 1.5 m3/h, rotameter capacity of 2-20 GPM/10- 70 LPM. The tool has been completed built and tested so it is feasible to use.*

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1. INTRODUCTION

Head Loss is the loss of mechanical energy per unit mass of fluid [1]. The unit of head loss is a unit of length that is equivalent to one unit of energy required to move one unit of fluid mass to a height of one corresponding unit of length[2]. There are two types of Head loss, namely major loss and minor loss. Major loss is the loss of flow caused by friction between the fluid and the walls of a straight pipe that has a fixed cross-sectional area, while minor loss is the loss of fluid flow in the pipe caused by the cross-sectional area of the flow, bends, bends, and so on [3] [4].

Design according to KBBI (Big Indonesian Dictionary) comes from the word design which means preparing something before the application process takes place or can also be called planning. Something that is planned contains a description that contains the procedure of the results of the analysis that has been carried out [3]. Based on the description above, when connected the word design and build has the meaning of realizing (building) what has been planned. In carrying out design and build analysis methods are needed to direct the design being worked on. The VDI 2221 method is one method that can be used to design the best design [5]. In this method there is a conceptual design stage that contains the steps for creating a complete function structure with constituent elements and their functions. The usefulness of compiling this system is called a sub-function and the relationship between one sub-function and another sub-function is combined and varied [4]. Flow loss test device already exist and are freely available on the market, but these tools have expensive purchase prices. Based on the description above, this study will design a tool that can be used to test flow losses in pipe installations using the VDI 2221 method[6].

2. METHODOLOGY

During the research there is a methodology or work flow of the research. The following is the methodology used in this research.

2.1. VDI 2221

Developed by Gerhard Pahl and Wolfgang Beitz, the VDI 2221 method was originally used for designing tool aids. VDI stands for Verein Deutscher Ingenieure, a systematic design method used to help ease the process flow in designing a product. In addition, this method is also useful for facilitating the learning process for a beginner and increasing the productivity of a designer in finding the best way to solve a problem [7][8].

A. Flow Method of VDI 2221

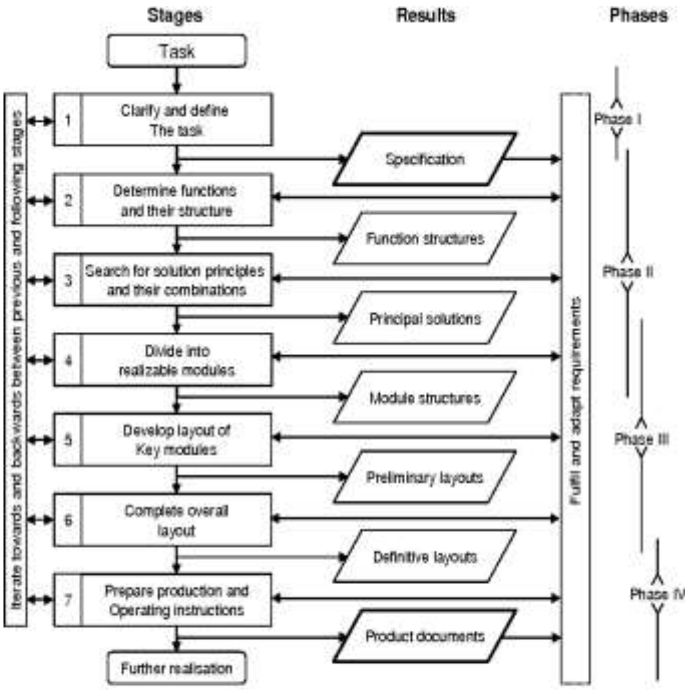


Figure 1. Flow diagram of VDI 2221

The VDI 2221 design method process is divided into several stages [7][8], that is :

a. Clarification of the task
   It is the collection of information or data about the requirements that will be met by the design of the tool and also its limitations.
b. Conceptual design
   Covers information on search function structures, suitable problem solving principles and combines them into variant concepts.
c. Embodiment Design
   The combination sketch of the solution principles that have been made is a form of initial layout, then selected which meets the requirements that are in accordance with the specifications and are good according to technical and economic criteria. The initial layout that is selected and developed into a definitive layout which is a form of design that is in accordance with needs and expectations. The definitive layout includes several things that are the results of this stage, including:
   • Form of a product element
   • Engineering calculations
   • Selection of shape and size
d. Detail Design
   This is the final step in the design. The results of the detailed design are in the form of documents that include machine drawings, detailed machine drawings, component lists, material specifications, operating systems, tolerances and other documents that are a single unit. Then a re-evaluation is carried out on the product, whether it really meets the specifications given.

B. Wishlist Determination

Decide on a wish list for the tool to be built. The following is a list of wishes for the tool to be made

Table 1. List of Wishes

No	Wishlist
1	Pump Capacity 300 watts
2	Water flow regulator (valve)
3	Pressure gauge
4	A flowmeter
5	Tee and elbow connection
6	Reducer
7	Several types of major loss pipes
8	Tool is easy to move
9	Process of making is relatively easy
10	Materials are easy to find in the market
11	Easy operation of the test equipment
12	Safe and environmentally friendly tools
13	Easy in component replacement
14	The maintenance are easy

C. Functional Structure

The structure of the function shows in the order that occurs in the functions related to the input and output of a system in determining the work tasks. It is a general description that shows the relationship between input and output. The relationship is translated into a block diagram as seen in the image below..

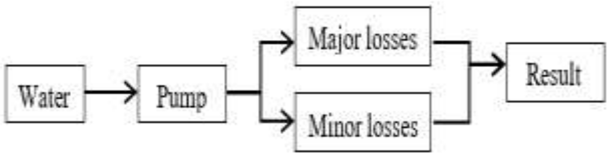


Figure 2. Main Functions

Based on the description of the function above, it is expected to provide an overview of the test flow of the tool to be made. From the explanation that has been explained above, there are several intentions that are expected to exist in the flow loss test tool that will be developed. The expectation of the test tool has the ability to:

a. Can measure the rate of water flow through the system
b. Can read major losses and minor losses
c. Can read the resulting losses
d. There is a valve as a flow regulator

2.2. Lost of Flow

In piping, there are flow losses caused by several factors including friction with the pipe, pipe flow turns and pipe flow cross-sectional width. Here are some of the losses contained in the pipeline.

A. Major Losses

The major disadvantage is in the straight flow of the pipeline [9].

$$hf = f\frac{L\,V^2}{D2g} \quad (1)$$

$$f = 64/Re \quad (2)$$

Information:

hf = Major loss
f = Friction factor from moody diagram
L = Pipe lenght (m)
v = Water flow rate (m/s)
D = Pipe diameter (m)
g = Acceleration of gravity (m/s^2)
Re = Reynolds number

In addition to using this formula, there are other formulas that can be used to calculate flow losses in straight pipes. The formula is known as Hazen William's equation [10].

$$Q = 0.2785 \cdot C \cdot D^{2.63} \cdot S^{0.54} \quad (3)$$

$$S = \frac{H_l}{L} \quad (4)$$

$$H_l = \left[\frac{Q}{0,2785 \cdot C \cdot D^{2,63}}\right]^{1,85} \cdot L \quad (5)$$

Information:
Q = Discharge (m^3/s)
C = Hazen William's Coefficient
S = Headloss per pipe length

The coefficients of Hazen William can be seen in the following table.

Table 2. Hazen William's Coefficient [10]

No	Material Pipa	Chw (m0,370211/det)
1	PVC	150
2	Cement, Iron lining pipe	140
3	Steel (elded steel)	130
4	Wood, concrete	120
5	Clay, new steel lining	110
6	Printed iron (old)	100
7	Corroded printed iron	80

B. Minor Losses

Minor losses occur due to changes in flow such as turns, branches, or passing through valves [9].

$$h_m = K \frac{V^2}{2g} \quad (6)$$

Information:
hm = Minor loss
K = Coefficient of loss

Table 3. Coefficient of Loss

Component	K	Component	K	Component	K
Elbows		***Tees***		*Angle, fully open*	2
90 *Short Elbow, flanged*	0.3	*Line flow, flanged*	0.2	*Gate, fully open*	0.15
90 *Short Elbow, threaded*	1.5	*Line flow, threaded*	0.9	*Gate, 1/4 closed*	0.26
90 *Long Elbow, flanged*	0.2	*Branch flow, flanged*	1.0	*Gate, 1/2 closed*	2.1
90 *Long Elbow, threaded*	0.7	*Branch flow, threaded*	2.0	*Gate, 3/4 closed*	17
45 *Long Elbow, flanged*	0.2	*Union, threaded*	0.08	*Swing Check, forward flow*	2
45 *Short Elbow, threaded*	0.4	***Valves***		*Swing Check, backward flow*	∞∞
		Diaphragm, fully open	2.3	*Ball, fully open*	0.05
180 *Return*		*Diaphragm, 1/4 closed*	21	*Ball, 1/3 closed*	5.5
180 *Return, flanged*	0.2	*Diaphragm, 1/2 closed*	4.3	*Ball, 2/3 closed*	210
180 *Return, threaded*	1.5	*Globe, fully open*	10	*Water meter*	7

C. Pressure Drop

Pressure drop is a term used to indicate a decrease in pressure in the flow of fluids. Systematically the descent for horizontal pipes is as follows

$$\Delta P = \rho \cdot g \cdot \Delta h \qquad (7)$$

Information:
ΔP = Pressure drop (N/m^2)
ρ = Fluid density (Kg/m^3)
Δh = Height difference on pressure gauge

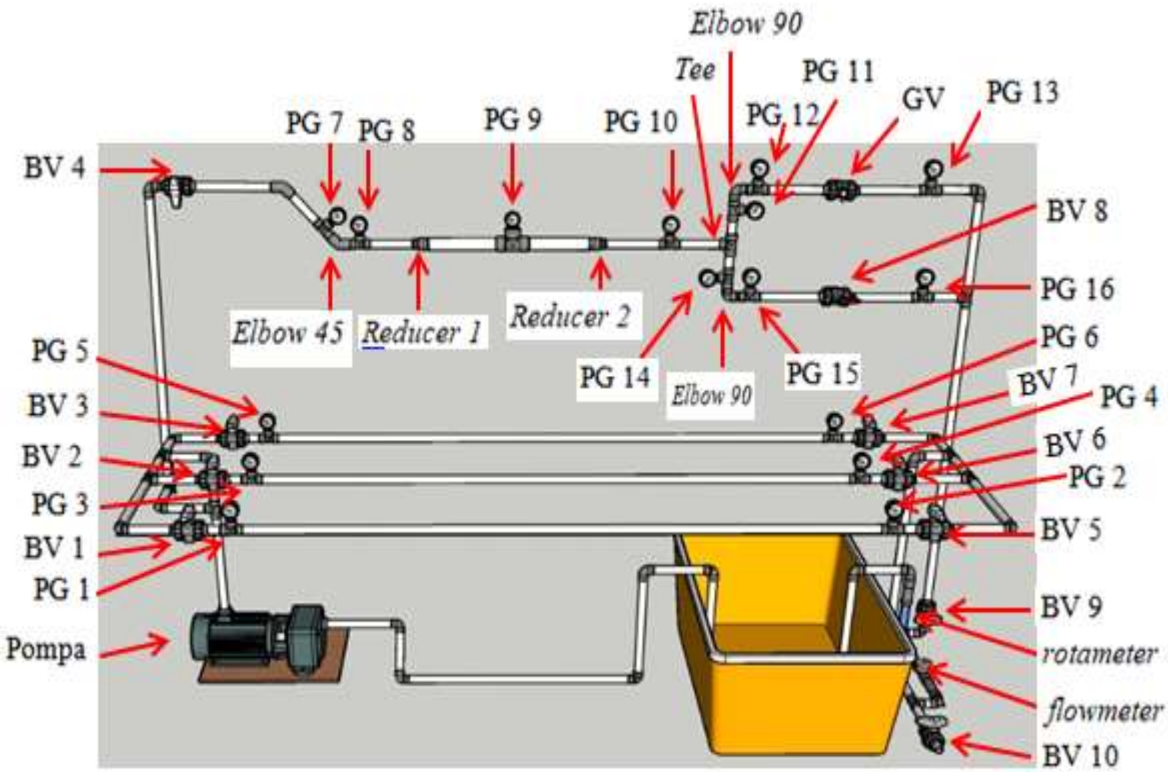


Figure 3. Test equipment expectations

Information:
PG = Pressure gauge
BV = Ballvalve

3. RESULT AND DISCUSSION

From the description of the methodology, the results of the research are as follows

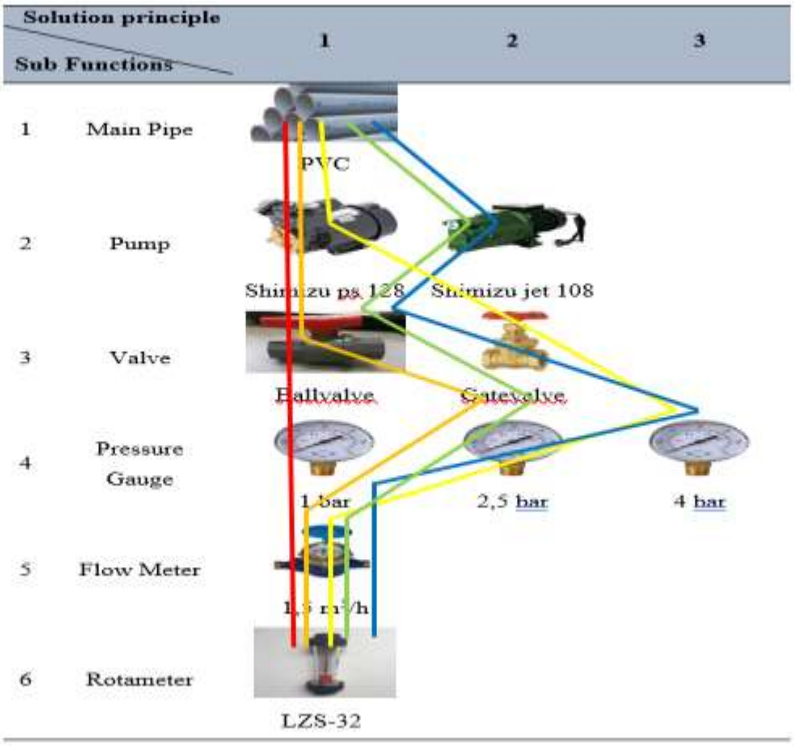
3.1. Abstraction

Abstraction is the formulation of problems and analysis of the wishlist. The steps to create an abstract
1. Eliminate all W-wishes
2. Ignore the will that has no direct relationship to the main functions and constraints
3. Transform quantitative data into qualitative data and reduce it into basic and quality statements only
4. The results of step 3 are made to be more general.
   a. The tool can be used as a flow loss test tool on various paths, both major and minor loss tests.
   b. The components of the tool can be easily assembled.
5. Solving problems to be neutral or solution-free

3.2. Solution Matrix

The search for solutions is intended to meet needs based on a list of wishes that have been made. The search for a solution is carried out by comparing several components that will then be obtained in combination from the functional structure.

Table 4. Solution Matrix



Based on the description in the table above, the following is a description of each variation that has been shown in table 3 above.

1. Red line : 1.1; 2.1; 3.1; 4.1; 5.1; 6.1
2. Orange line : 1.1; 2.1; 3.1; 4.2; 5.1; 6.1
3. Yellow line : 1.1; 2.1; 3.2; 4.3; 5.1; 6.1
4. Green line : 1.1; 2.2; 3.1; 4.2; 5.1; 6.1
5. Blue line : 1.1; 2.2; 3.1; 4.3; 5.1; 6.1

3.3. Variety Selection

The selection of variations will take into account all aspects that are felt to be appropriate to be combined with existing options in order to become an optimal system.

A. Pump Selection

In the table there are 2 options for the pump to be used, here is a comparison between the two pumps.

Table 5. Pump Comparison

SPECIFICATIONS	PUMP TYPE (BIT)	
	Shimizu PS 128 BIT	Shimizu JET 108 BIT
Output (W)	125	150
Input (Kw)	0.3	0.35
Suction Power Max (m)	9	11
Total Head Max (m)	29	30
Maximum Capacity (L/min)	24	50
Head (H)	20 | 10	21 | 5
Debit (Q)	10 | 18	7 | 50
Input Pipe (inch)	1	1
Output Pipe (inch)	1	1
Weight (Kg)	7	13

Based on the description of the comparison above, the shimizu JET 108 BIT pump has advantages in suction power and total head. In terms of the capacity that can be produced, it reaches 50 liters per minute. Therefore, the Shimizu JET 108 BIT pump was chosen to be used in a series of test equipment.

B. Valve Selection

In the variation matrix there are 2 types of valves that are likely to be used in a series of test equipment. The following is a comparison of the capabilities of the two valves.

Table 6. Valve selection

Valve Type	Blocking Isolate	Regulating Flow	Prevent Backflow	Size	High Pressure
Globe	**	***	x	*	**
Ball & Plug	***	*	*	*	**

Based on the description above, the use of ball valves is more possible because it is superior in ability. In addition to its superior capabilities, the use of ball valves is easier and more practical than globe valves.

C. Pressure Gauge Selection

Calculations will be done separately for before and after the pump.

a. Before Pump

The equation to be used is

$$(H_s - H_a - H_{loss}) \cdot \rho \cdot g = - P_1$$

Known:

Q = 50 $liter/\sec$ = 0,00083 m^3/sec
Hs =11 m
L = 243 cm = 2,43 m
D = 1 inci = 0,0254 m

Calculating the cross-sectional area of a flow pipe
A = π/4 $(D)^2$
A = 3,14/4 $(0{,}0254\ m)^2$
A =0,00051 m^2

Calculate the speed of water flow
v=Q/A
v=(0,00083 m^3/s)/(0,00051 m^2)
v= 1,63 m/s

The calculation of losses uses Hazen William's equation as follows

$$H_l = \left[\frac{Q}{0{,}2785 \cdot C \cdot D^{2{,}63}}\right]^{1{,}85} \cdot L \qquad (5)$$

$$H_l = \left[\frac{0{,}00083}{0{,}2785 \cdot 150 \cdot (0{,}0254\ )^{2{,}63}}\right]^{1{,}85} \cdot 2{,}43\ m$$

$$H_l = 0{,}28\ m$$

The suction pipe is not straight, there are several turns so the calculation of losses for pipe 90^0 is as follows:

$$H_b = K\frac{v^2}{2 \cdot g} \qquad (6)$$

$$H_b = 0{,}3\frac{0{,}94^2}{2 \cdot 9{,}8}$$

$H_b = 0{,}0135\ m$ for 1 turn
$H_b = 0{,}0675\ m$ for 5 turn

Calculating the head speed out is as follows:

$$\frac{vd^2}{2 \cdot g} = \frac{1{,}63^2}{2 \cdot 9{,}8} = 0{,}14\ m$$

So that the number of the head loss on the inlet side of the pump is as follows:

$$H_{ltotal} = H_l + H_b + \frac{vd^2}{2 \cdot g}$$
$$= 0{,}28\ m + 0{,}0675\ m + 0{,}14\ m$$
$$H_{ltotal} = 0{,}49\ m$$

Calculating pump suction pressure

P1 = $Hs \cdot \rho \cdot$ g
=(11m-0,49m)·1000 kg/m^3·9,8m/s^2
=(11m-0,49m)·1019,7 N/m^3 ·9,8m/s^2
=105027 N/m^2
=-105027 Pa

b. After Pump
After the suction pressure is obtained, then it is then calculated the thrust pressure of the pump. The thrust pressure calculation is as follows

$$H_P = \frac{P_2 - P_1}{\rho g} \quad (7)$$

Known:
$H_P = 21\ m$
$P_1 = -105027 N/m^2$
ρg= 9993,1 N/m^3

$$21\ m = \frac{P_2 - 105027\ N/m^2}{9993{,}1\ N/m^3}$$
$$21\ m = \frac{P_2 - 105027\ N/m^2}{9993{,}1\ N/m^3}$$
$$21\ m \times 9993{,}1\ N/m^3 = P_2 - 105027\ N/m^2$$
$$209855\ N/m^2 = P_2 - 105027\ N/m^2$$
$$P_2 = 104828 \frac{N}{m^2} = 1{,}05\ Bar$$

From the results of the calculation above, the selection of the pressure gauge must be above the calculation, then what can be chosen is a pressure gauge with a capacity of 2.5 bar.

3.4. Selection of Variation Results
After taking into account, the variations are then considered and studied as seen in the table below.

Table 7. Selection of Variation Results

Bachelor Engineering Mercu Buana University	SELECTION TABLE **Flow Loss Testing Device in Pipe Installation**							
(+) Yes (x) No (?) Lack of information (!) Check Specifications	DECISION (+) Yes (x) No (?) Lack of information (!) Check Specifications							
	A according to the whole desire	B can be realized	C meet agreed limits	D Safe to use	E Clear information	F Liked by members	Information (indication, reason)	
Red	+	X	+	X	+	+	according of practicality and safety	X
Orange	+	X	+	X	+	+		X
Yellow	+	X	X	+	+	+		X
Green	+	+	+	+	+	+		+
Blue	+	+	+	x	+	+		X

From the description above, the variation in decisions is guided by several factors, including:

a. Availability of materials in the field
b. Ease of assembly and maintenance
c. Ease of operation
d. Material lifespan
e. Conformity with wishlist

From the data that has been obtained above, the green variety is obtained as the best variety.

3.5. Test Equipment Assembly

The initial stage that must be done is the collection of tools and materials that will be used to build this test equipment. The tools and materials that have been collected are then cut according to the predetermined size, assembled according to the design that has been determined and then glued using glue. For the use of drat, before being assembled, it is coated first using seal tape to avoid leaks. The assembly process can be directly carried out on the frame that will support the load of the flow loss test equipment in this pipeline installation. Pictures of the assembled test equipment can be seen in the picture below.

Figure 4. Test Equipment

The tool has been successfully made, the next step is to conduct a feasibility test on the tool that has just been built. The test results can be seen in the table below.

Table 8. Tool Testing

No	Test Items	Resistance		Information
		Yes	No	
1	Connection leaks	v		No leakage
2	Valve function	v		Work as it works
3	Pressure Gauge	v		Can read pressure
4	Flowmeter	v		Can read the flow of water
5	Rotameter	v		Can read the flow discharge

From the tests that have been carried out, there are no leaks in any of the existing joints. The valve functions as it should to close and open the fluid flow system. The pressure gauge can read the pressure at each predetermined point. The flowmeter and rotameter can read the flow rate that passes through this test equipment system.

4. CONCLUSION

From the research that has been carried out, the following research results are obtained:

a. From the results of the selection of variations, the results were obtained: the use of PVC pipes as the main pipe, the pump using a 108-bit shimizu jet, the main valve using a balvalve, the pressure gauge using a capacity of 2.5 bar, the flowmeter using a capacity of 1.5 m3/h, and the rotameter using a capacity of 2-20 GPM/10-70 LPM.
b. Flow loss test equipment in pipeline installations has been successfully made using the VDI 2221 method with green variation as a suitable variation and has been carried out a feasibility test so that the tool can be used to test flow losses in pipeline installations.

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