Numerical Analysis Dynamometer (Water Brake) Using Computational Fluid Dynamic Software

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Abstract

One of the most popular internal combustion engines is the engine in the transportation device. Power is a parameter that shows the capabilities of an object that gives energy, for example the internal combustion engine. Power in this engine is measured by a device called dynamometer. The CFD (Computational Fluid Dynamic) fluent software was simulated several impeller variables to absorb power of engine. With that result, we knew the biggest dynamometer absorber power, cheapest and easy to be made. The hydraulic dynamometer is selected type of dynamometer as the result of design process. The basic principle of a hydraulic dynamometer is the same as centrifugal pump but it has low pump efficiency. The results of the test are maximum power and torque of the tested engine and the operation area of the selected hydraulic dynamometer.

Key words: hydraulic dynamometer, impeller, CFD Fluent, power and torque.

1. Introduction

Combustion engine is one of heat engine type which applied in many sectors (transportation, industry, power station, etc). Combustion engine power is important to be known to measure working performance of engine.

Work performance of fuel combustion engine is known using power measuring device. Power measuring device which the most applied and has popular in many market is dynamometer. Work principle of dynamometer is by giving resistance at rotation of crank shaft, torsion effect measured and power combustion engine will know through calculation.

In this paper, The writer tries to simulate performance of absorption dynamometer water brake type with numerical method. It is used to measure fuel combustion engine with computer software which has been developed and popular.

Numerical method has more advantages, compared with experiment method. It obtained various data, cost relative cheap, time setup relative short and it has not influenced with environment factor. In this paper FLUENT software used as basic simulating program. It is included in Computational Fluid Dynamic category or CFD Software. Numerical method in this software can solve involutes geometry and boundary conditions, which is resisted in experiment method. FLUENT is one of the software CFD. Its principle work based on the finite volume method.

2. Theoretical Analysis

The dynamometer used to measure performance combustion engine. Work principle of dynamometer is torsion as result from rotation engine.

Hydraulic Dynamometer

Hydraulic dynamometer is one of absorption dynamometer. It used fluid to absorbed power engine (hydraulic system) see (figure 1). Water usually applied as fluid, where it is function as coolant and lubricate media. Hydraulic dynamometer has two important components that are moving vane (rotor) and steady vane (stator).

Rotor is rotated from engine through an axis. Spin of rotor will give effect suction in the dynamometer. Water comes from outside to the dynamometer through the two inlets. Water and rotor rotated together. While rotating, water gave friction effect with rotation of engine and heat appears. The water flow continually trough casing are important to decrease heat and as lubricate between seal and axis. Stator and casing are joining permanently. The arm is attached with casing, where at the end of arm added measuring instrument. Using calculation result from measuring instrument can be found torsion.

Water from dynamometer is not enabled exceeds 80ºC. Water supply pumped must clean, cool, and obtainable constant.

Advantages of hydraulic dynamometer are:

a. Doesn't require permanent installation
b. Easy to remove out from one machines to other machine (portable).
c. Only need one operator
d. Have large range of power and speed.

When idle, position of measuring instrument must show zero number (dynamometer in balance). Measuring rotation of axis engine needed to get performance of combustion engine. Its done to avoid dynamometer broke. [2]

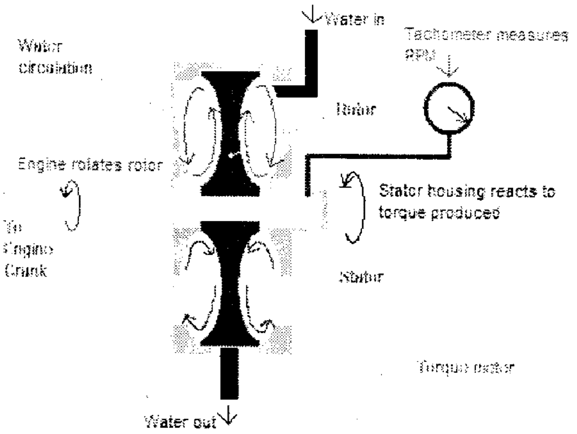


Figure 1 Hydraulic Dynamometer (Ref.8)

Calculating absorption impeller Power

Power calculations are axis power and lost friction power in disk.

1. Axial power

Rotation moment will get power same as like power giving to axial P = M.ω. where ω is angel velocity. Axial power can be express by:

$$P = \rho . Q . r_2^{\ 2} . \omega^2 \quad (1)$$

a. Lost friction power (disk)

Fluid (liquid) at rotated surface disk and casing move out from disk. It' s happened because rotation friction force and radial centrifugal force appeared.

$$Pf = 160\left(\frac{n}{1000}\right)^3 d^5 = 0.0011 u^3 d^2 \quad (2)$$

a. Fluid force equation is given by :

$$P_{fluid} = \rho . Q . g . H \quad (3)$$

The impeller efficiency can be expressed by:

$$\eta = \frac{P_{fluid}}{P_{mech}} x100\% \quad (4)$$

3. VARIABEL SIMULATION IN FLUENT

Description problem

At this simulation will be presented stream pattern at dynamometer with various impeller distance to wall (Sr), Height Impeller (Tr), number of impeller (Zn), number of rotations impeller (n) and inlet flow debit (Q). Specification of dimension from impeller is shown in Fig.3.

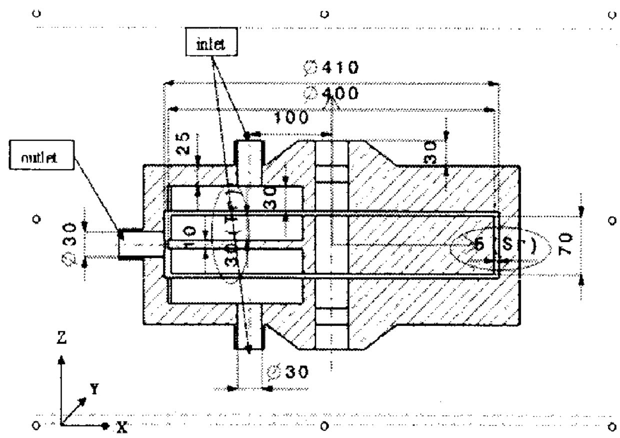


Figure 3 Dinamometer Impeller B Type (blade in casing)

Speed of impeller rotary equal with speed of machine rotary (n) and flow rate (Q). Water fluid enters through inlet and exit through outlet. During inside at dynamometer, impeller with water rotating together and decrease speed rotation of engine (Water Brake). This phenomenon will generate torsion. It is measured at center rotation with direction of axis Z.

Operating condition

At this simulation fluid material applied as references are:

Fluid type = water (H2O-liqid)

Temperature = 27^0 C

Fluid Density = 998,2 kg/m2

Fluid absolute viscosity = 0001003 kg/ms

Debit inlet fluid = 1,5 gpm

Velocity rotary impeller = 3600 rpm

Boundary condition

At this simulation boundary condition specified as follows:

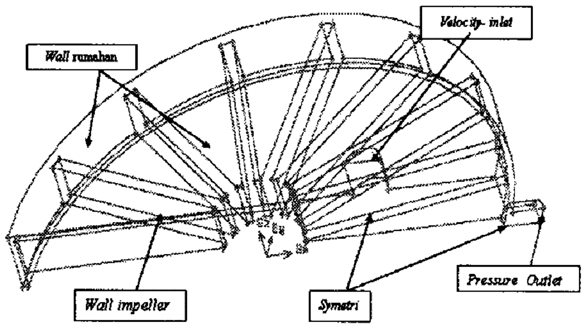


Figure 4 Boundary condition

Grid simulation in Gambit

Grid simulation basically is done to get a good grid structure. It can predict complex stream pattern with a little number of cells. This setting structure obtained by doing various adaption. Pressure interpolation scheme is default option in Fluent. It is used to adapt Entirety of simulation process. Flow fluid in dynamometer simulation is turbulent flow.

The calculation of pump theory

Dynamometer type water brake can be analogy as water pump with small efficiency pump. Using equations of the pump theory with same boundary condition and variable input will result power absorption impeller. This power absorption impeller can compare as validation calculation numeric. Calculation of absorption impeller is given by:

Power Axis

For calculation power given axis must pay attention to speed triangle, see figure 5. The speed triangle enter (β_1) = 90° . If it is compared to exit blade angle 20 º - 80° , *exit blade angle (c_2) 90º* has absolute speed out and the biggest increase height (head).

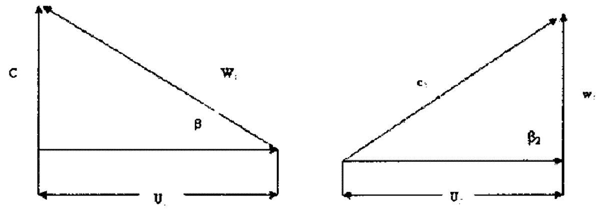


Figure 5 Speed triangle entering (β2) = 90° and speed triangle exit (β2) = 90°.

Power Axis:

$$P = \rho . Q . r_2^{\,2} . \omega^2$$

$$P = 1000.0{,}001.(0{,}2)^2 . (376{,}8)^2$$

$$P = 5732{,}13 \text{ Watt} = 7{,}68 \text{ hp}$$

Where: $\omega = \dfrac{2.\pi.n}{60}$

$$= \frac{2.3{,}14.3600}{60}$$

= 376,8 rad/det

Lost friction power (disk):

$$Pf = 160\left(\frac{n}{1000}\right)^3 d^5 = 0.0011 u^3 d^2$$

$$= 0{,}0011.(75{,}36)^3 .(0{,}4)^2$$

= 75,32 hp

Where :

u = Volocity circumference disk (m/s)

$= \frac{2.\pi.r.n}{60}$

$= \frac{2.3.14.0,2.3600}{60}$

= 75,36 m/det

Absorption impeller power

P_{total}= power axis(P) + lost friction power (P_f)

= 7,68 + 75,32

= 84,00 hp

(Head)

$$H = \left(\frac{n.Q^{\frac{1}{2}}}{Nq}\right)^{\frac{3}{4}}$$

$$H = \left(\frac{3600.(1,01)^{\frac{1}{2}}}{2000}\right)^{\frac{3}{4}} \qquad H = 2,2 \text{ m}$$

Asumsi :

Nq = spesifik velocity (1/minut)

[2000 (1/minut) chosen for calculation]

Daya fluida (P_{fluid})

$$P_{fluid} = \rho.Q.g.H$$

$$= 1000.0,001.9,81.2,2$$

= 21,77 watt

Impeler efficiency:

$$\eta = \frac{P_{fluid}}{P_{mech}} x100\%$$

$$\eta = \frac{21,77}{5732,13} x100\% \quad = 0,38\ \%$$

Result of simulation setting nearest approach calculation to the pump theory is selected to analyze various dynamometer variables. K-epsilon model using *Descretization Second Order* for *pressure, Quick* for momentum and *Two-Layer Zonal Model* for *Near wall Treatment* gives resulted torsion calculation with the pump theory, table 1. It is 8577 Hp, reached with 2990 times interpolation.

Tabel.1 Solution model

Solver	*Segregated*
Calculation Method	*Steady*
Viscous Model *RNG Model*	*k ε RNG* *Differential Viscosity Model*
Near Wall Treatment	*Near wall treatment*
Discretization: *Pressure* *Momentum*	*Second order* *Quick* *Quick*
Pressure Velocity Coupling	*simple*
Kriteria Konvergensi	0.000001

Grid simulation is done to obtain a good grid structure. It is used to predict stream pattern with a little number of cells.

The Result of Impeller Simulation Type B

Dynamometer modeling simulation is needed high performance of computer. It is influence required much longer time analysis. The symmetry method can solve both of problems without decreasing accuracy.

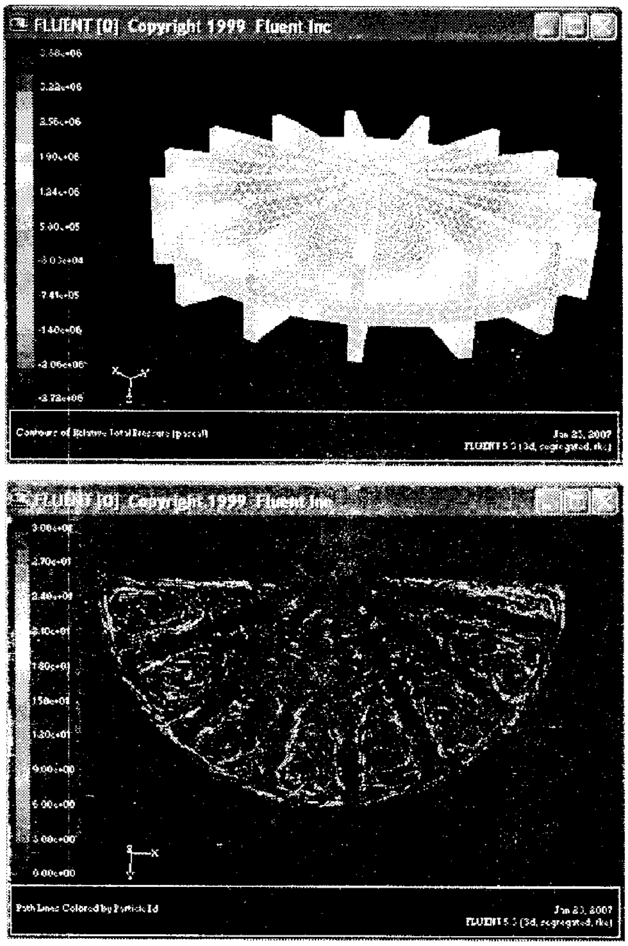
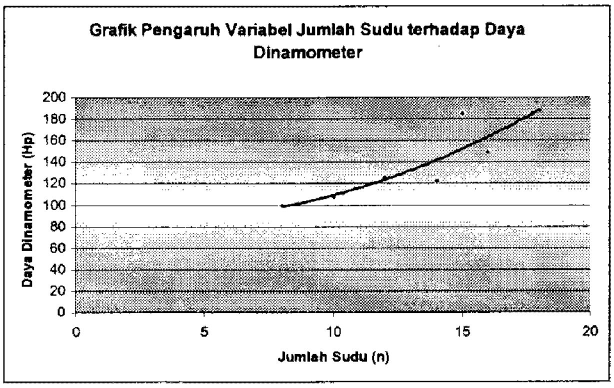


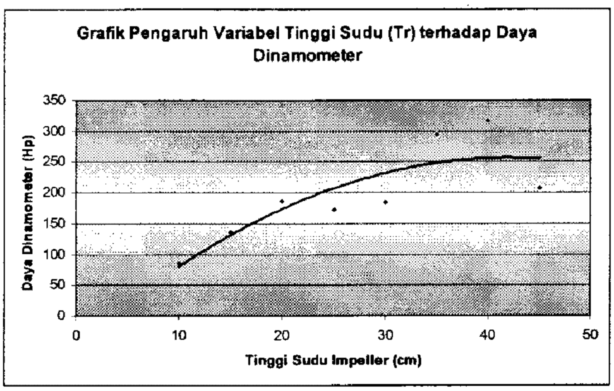
Figure. 7 (a) Total Pressure Distribution at Impeller and (b) Pathline Fluida Partikel Motion at cut field 25 mm from Z axis

This rotary stream pattern happened in space between rotor and stator. It caused of angular force as result of rotary impeller see figure.7. The effect of rotary impeller can show at particle motion at X-axis cut area. Fluid particle at the end of impeller moved perpendicular with blade area and opposite with direction of motion impeller

Addition number of blades impeller to absorption power impeller shows increased stability enough. The blade amounts 18 and 20 power absorption differences reached smallest 105 and 111 Hp, this thing indicates that for amounts of blade more than 20 of power absorption reached stable.



(a)

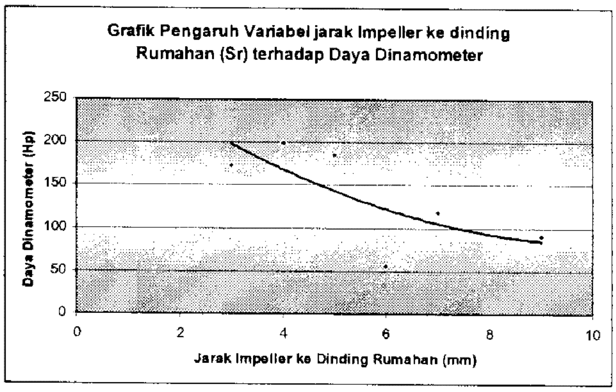


(b)

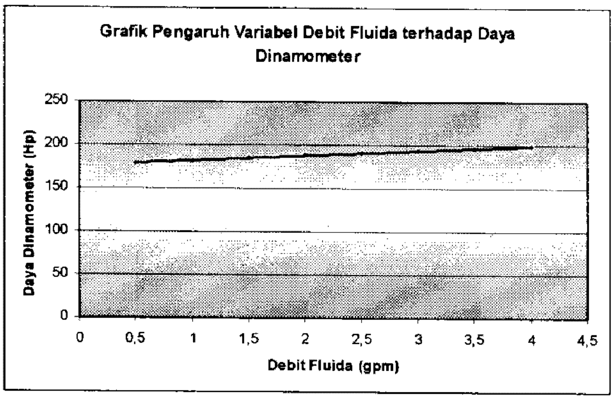
Figure 11 (a) Graphic effect numbers of blade impeller to the power absorb of impeller dynamometer type B. (b) Graphic the effect of blade impeller height to power absorb impeller dynamometer type B

Graphic influences numbers of blade to power absorb of dynamometer impeller type B have not reached stable point yet, as shown in Fig 11.a. Input variable data number of impeller is limited until 20, because that condition is faced difficulty in casting process and also machinery process.

At figure 11.b, shown increasing height of blade impeller caused the absorption increasing. However there is maximum limit height impeller at 20 mm. This is caused of no friction between water fluid particles with all surface of blade. It is happened only at the end of blade. It is shown pattern distribution pressure at figure 7. High addition impeller is also limited by strength material of impeller



(a)



(b)

Figure 12 (a) Graphic the effect of distance impeller casing wall to power absorb of impeller dynamometer
(b) Graphic effect flow rate of water fluid to power absorb of impeller dynamometer type B

In Figure 12.a, improvement of distance impeller to casing wall will influence incidence of friction force by fluid. Every greater parted impeller to casing wall will give effect decrease at impeller power absorption. At picture 12.b shows graph effect flow rate of water fluid to power absorb dynamometer absorption. During improvement flow rate of water fluid absorption reached increases also, but its change sufficiently small so that graphs approach to horizontal. It concludes that the increase of water flow rate doesn' t have effect with the increase of power absorption impeller.

Improvement Speed of rotation impeller will equivalent with improvement of absorption impeller. This improvement has limit point where improvement of rotation impeller will not increase of absorption impeller but tends to linear. At 3300 to 3600 rpm speed of rotation impeller change power absorb happened sufficiently small so this is stabile point. It is caused by centrifugal force of fluid big enough as result of rotation. That is reduced friction between water fluid and casing wall of impeller.

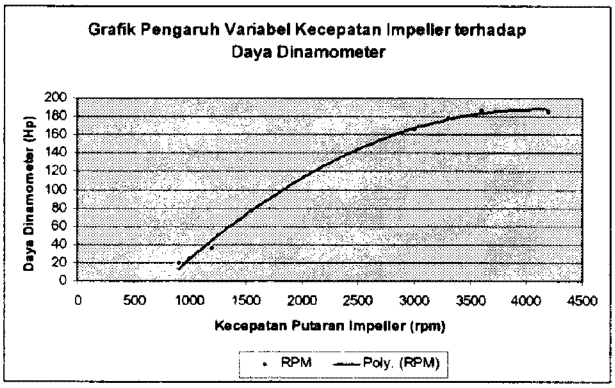


Figure 15 Graphic effect speed of rotation impeller to the power absorb impeller dynamometer

From selected variable simulation, the biggest dynamometer power but can be made with consideration of relative cost of cheap, strength of material and relative easiest machinery process.

5. Conclusion

1. **Simulation of Stream fluid at dynamometer type B using option *turbulent standard model, Second Order, Quick, SIMPLE* option approach that is appropriate for case *Swirl***
2. **Simulation of Stream fluid at dynamometer type B with the same set option given variable data as follows:**
   - At simulation variable number of blade, the biggest power absorbs reached 187,977 Hp at blade amounts of 18.
   - At simulation variable weight of impeller, the biggest power absorb reached 317,37 Hp at height impeller 40 mm
   - At simulation variable distance impeller to casing wall, the biggest power absorb reached 199,43 Hp at distance 4 mm
   - At simulation variable flow rate of water fluid, the biggest power absorb reached 198,635 Hp at 4 gpm
   - At simulation variable speed of rotary impeller, the biggest power absorb reached 185 Hp at rotation speed 3600 rpm
3. From data of simulation selected variable that have the biggest dynamometer power absorb and it can be made with consideration of cost, strength of material and machinery process. They are:

   Number of impeller is 15

   Height impeller is 30 mm

   Distance impeller to wall of casing is 5 mm

   Power of dynamometer capable to be absorbed 185 Hp
4. If compared with real experiment method, the difference between results in those methods big enough. This shown performance set option *turbulent standard model* in fluent. It needed further research using another turbulence model (*RMS= Reynolds Stress Model and LES=Large Eddy Simulation*) to get the best set option in fluent.

Nomenclature

η	=	effisiency (%)
H	=	head (m)
g	=	acclerated of gravity (m/s^2)
M	=	moment (N.m)
r	=	radius (m)
Q	=	water flow rate (m^3/s)
m	=	mass (kg)
ω	=	velocity angel (rad/s)
D,d	=	diameter (m)
P	=	power absorb (hp)
n	=	rotaion (rpm)
ρ	=	Density (kg/m^3)

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