Fluid Flow Particularities within Hydraulic Working Circuit

Assistant professor PhD Eng. **Fănel ȘCHEAUA**[1]

[1] Dunarea de Jos University of Galati, Domneasca Street 47, e-mail: fanel.scheaua@ugal.ro

Abstract: *As is known from the principles of fluid mechanics, the flow phenomenon of the working fluid within a hydraulic circuit is always accompanied by energy losses that are inevitably determined by the frictional forces with the pipe walls, the geometric shape of the pipeline used in the circuit but also the inner walls roughness of the circuit pipeline which interacts with the fluid. The fluid environment is used within the hydro-static systems in order to transmit the energy representing the support which, by simply circulating in the circuit to the execution organs, causes different device movements (rotation or translation) as a result of directly action. Forced flow of the working fluid inside the circuit is a complex phenomenon of continuous or non-permanent flow which involves the general laws and equations of the customized fluid mechanics for specific working situations of the hydro-static drive systems.*

Keywords: *Fluid, flow, laminar, turbulence, simulation, three-dimensional modelling*

1. Introduction

It is known that hydraulic and pneumatic drives have seen an unprecedented development in recent years due to increased use in the working systems of machines and equipment used in most industrial branches. At present time there is no industry branch that does not benefit from the supply of hydraulics and/or pneumatics in order to perform various tasks that simplify user activities.
Thus, industrial applications are known related to systems in stationary equipment involving fixed machines such as hydraulic presses, molding hammers, or various cutting equipment, as well as equipment present in mobile machinery represented by excavators, loaders, self-drilling, bulldozers and mowers.

2. Model of laminar flow for the working fluid

The hydro-static driving system is designed as a system that can operate permanently, the flow of the working fluid takes place within a working circuit that consists of active components (pump, motor) but also other components that allow the adjustment of the pressure values or flow rate in the circuit.
The flow pattern of the working fluid within the circuit pipelines can be considered laminar if the fluid viscosity is at a high level, the flow diameter is small relative to the duct length in which the flow occurs, or the fluid velocity is below the admissible limit value. Since mineral oil is mainly used in hydro-static drive circuits, the admissible flow velocity is up to 12 m/s. The usual circulating oil velocity values inside the driving circuit lines are in the range of 5-8 m/s.
Due to the adhesion forces occurring at the contact surface between the working fluid and the pipe walls, the change phenomenon of the circulation velocity values occurs as the fluid moves inside the pipe (Figure 1).

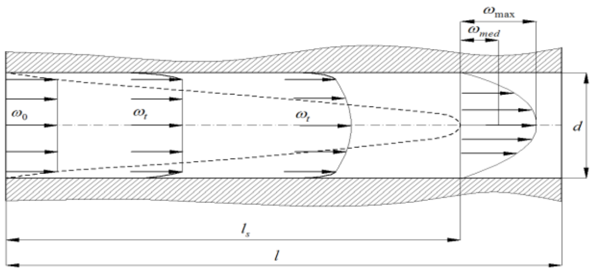


Fig. 1. Laminar flow model inside a circular pipeline

The continuous change in the flow velocity through the pipe is possible up to the pipeline axis when a parabolic distribution of flow velocity values is encountered (Hagen-Poiseuille) and the pipe length at which these velocity values changes occur is considered a stabilization length that can be calculated using the relationship: [1], [3]

$$l_S = 0.0575 \cdot d \cdot \mathrm{Re} \tag{1}$$

where d- pipe diameter;
Re – Reynolds number (adimensional);

$$\mathrm{Re} = \frac{\omega_{med} \cdot d}{\upsilon} \tag{2}$$

ω_{med} - average velocity value;
υ – fluid kinematic viscosity.
The average flow velocity of the working fluid within a hydro-static system can be assumed according the following relation:

$$\omega_{med} = \frac{Q_p}{A_n} \tag{3}$$

where:
Q_p – the pump volumetric flow rate;
A_n –cross-sectional area of the pipe.
Load losses during the flow of the working fluid through the hydrostatic actuator system pipeline are described as pressure drops generated by fluid inertia forces and viscosity forces. Darcy's relationship describes the pressure drop across a pipeline between two points: [1], [3]

$$\Delta_p = p_1 - p_2 = \lambda \cdot \frac{\rho}{2} \cdot \frac{l}{d} \cdot \omega_{med}^2 \tag{4}$$

Δ_p – the pressure drop on the pipe;
ρ - fluid density;
l,d – length and nominal pipe diameter;
ω_{med} – average flow velocity;
λ - linear loss coefficient.
During the operation of the hydrostatic system, the load losses (pressure drops) must be defeated by the actuator pump. The specific load loss linear coefficient parameter describes the losses magnitude in the isothermal or non-isothermal laminar flow regime specific to the hydrostatic drive circuit. The laminar flow regime for a fluid is evaluated by the Reynolds limit number having a value of Rel = 2320 value, and for mineral oils used predominantly Rel relays about 2000.

3. Turbulent flow pattern of the working fluid

For the turbulent flow model of the working fluid the laminar boundary layer at the pipe inlet becomes immediately turbulent increasing towards the pipe center of over a stabilizing length of about 25-40 pipe diameters. (Figure 2).

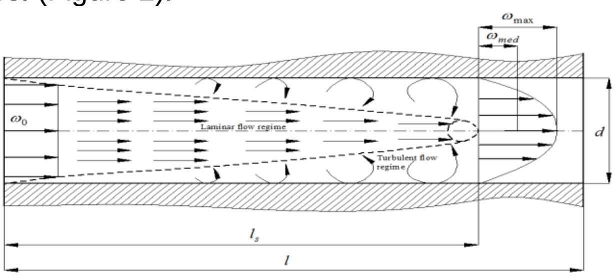


Fig. 2. Turbulent flow model inside a circular pipeline

For the turbulent flow model the Reynolds number is characterized by Re> 2320 or Re> 2000 for mineral oils. For the turbulent flow model, the load losses (pressure drops) on the grid are evaluated by the Darcy equivalent relationship, being heavily influenced by the roughness of the pipe walls, the working agent temperature and the hydraulic circuit path geometry.

The loss factor can be computed with Blasius, or Prandtl-Karman: [1], [2]

- Blasius for $4 \cdot 10^3 < \mathrm{Re} < 10^5$

$$\lambda = \frac{0.3164}{\sqrt[4]{\mathrm{Re}}} \quad (5)$$

- Prandtl-Karman for $3 \cdot 10^3 < \mathrm{Re} < 10^7$

$$\frac{1}{\lambda} = \frac{2}{\rho} \cdot \mathrm{Re} \cdot \sqrt{\lambda} - 0.8 \quad (6)$$

4. Fluid flow simulation on the virtual model

The fluid flow simulation on the circular pipeline model is accomplished on virtual three-dimensional model. The velocity circulation is declared in the range of 5 and 7 m/s corresponding to the specific velocity of the working fluid within a hydrostatic actuation system.
The reference pressure is 300 bar, the working fluid density is 900-905 kg/m3 (mineral oil), and the viscosity specific to mineral oils is in the range of 17-63 cSt, (table 1).

Table 1: Mineral oil properties

Mineral oil	H18A	H32A	H46A	H60A
Kinematic viscosity (cSt)	17-21	27-33	44-49	58-63
Density (g/cm3)	0.900	0.900	0.905	0.905

The pipeline diameter values are presented in table 2.

Table 2: Inner diameter values for pipeline

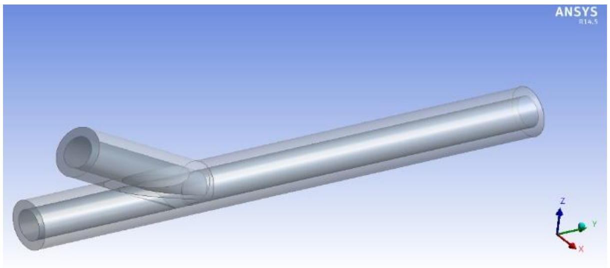
Duct inner diameter					
6.5	8	10	13	16	19

The pipeline virtual model analysis was designed to view the speed, pressure and flow pattern of the working fluid.
The model is a circular duct with two inlets and an outlet, the inside diameter is 19 mm and the total length is 300 mm, the working fluid is a mineral oil (H32A, H60A) having a density of 0.900 and 0.905 g/cm3, the kinematic viscosity of 33 and 63 cSt.
Four distinct cases were analysed in which specific rates of inlet velocity as well as kinematic viscosity values of the working fluid were reported (Table 3).

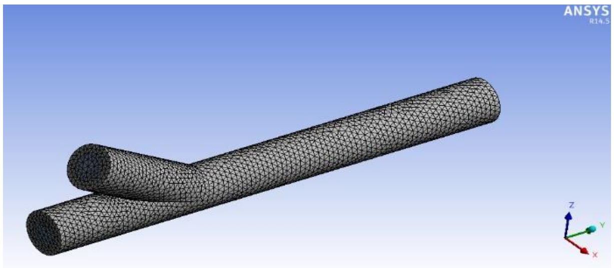
Table 3: Initial data for the four cases

Case number	**Fluid density (kg/m3)**	**Kinematic viscosity (cSt)**	**Inlet velocity 1 (m/s)**	**Inlet velocity 2 (m/s)**
1	900	33	3	5
2	900	33	5	7
3	905	63	3	5
4	905	63	5	7

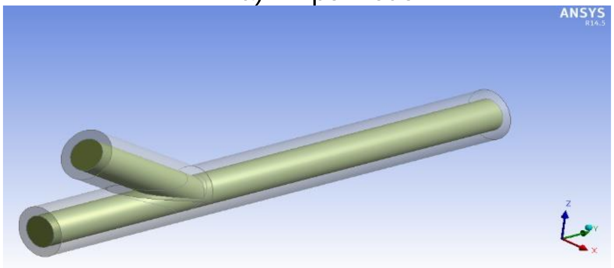
The model used for the analysis is shown in Figure 3, along with the meshing network and solid and fluid domains in the model assembly.



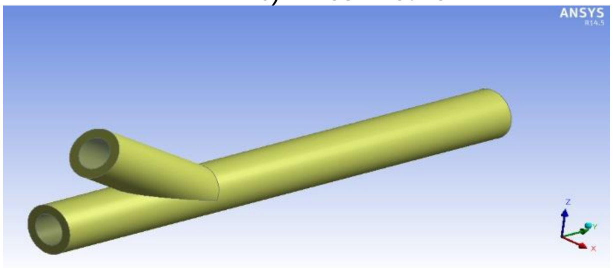
a) Pipe model



b) Mesh network

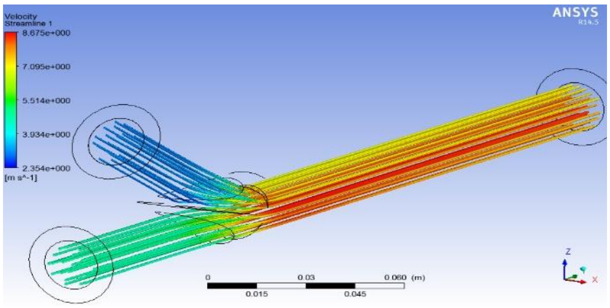


c) Fluid domain

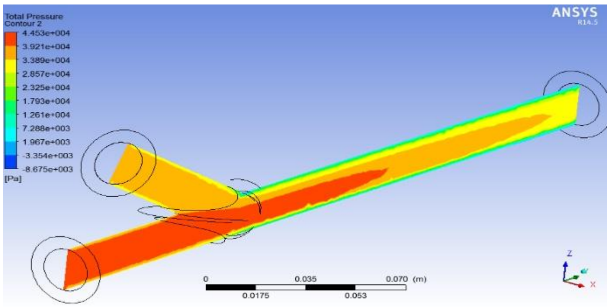


d) Solid domain

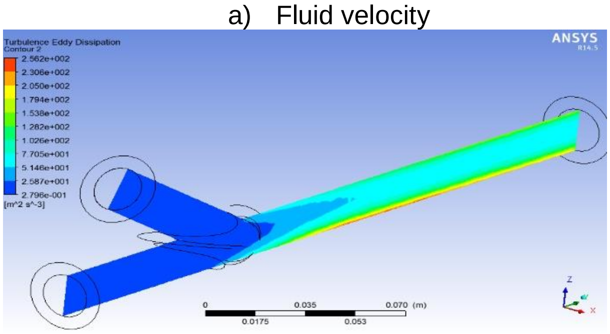
Fig. 3. Three-dimensional model for the pipeline



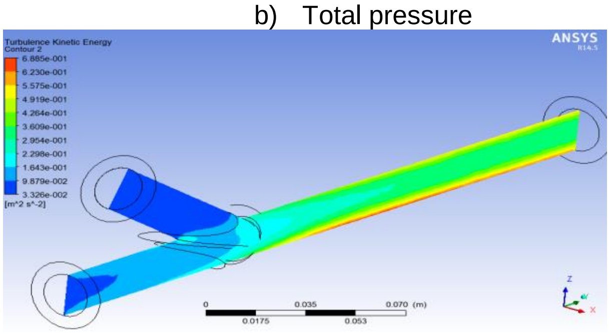
a) Fluid velocity



b) Total pressure

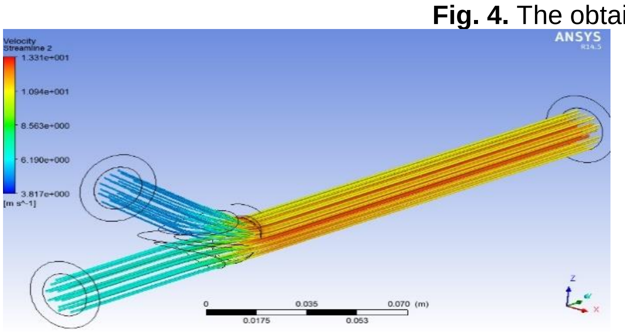


c) Turbulence eddy dissipation

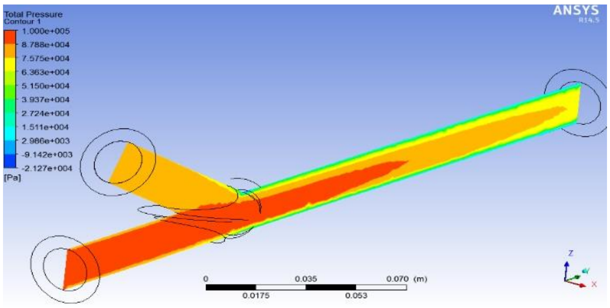


d) Turbulence kinetic energy

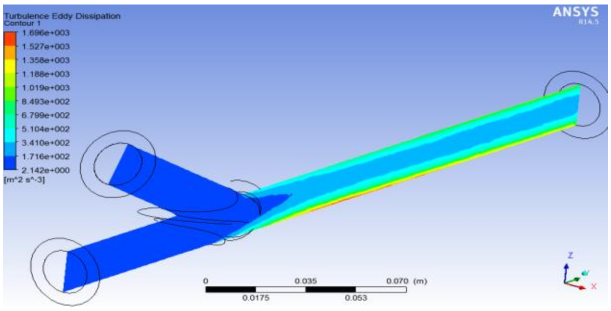
Fig. 4. The obtained results for case 1



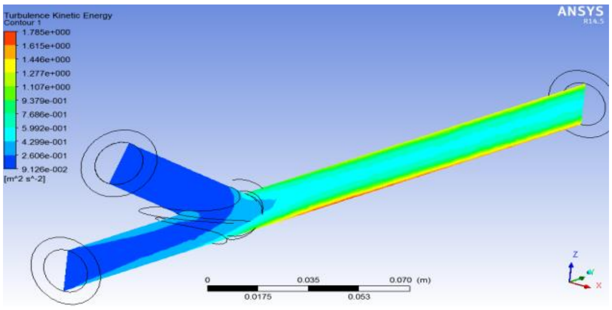
a) Fluid velocity



b) Total pressure

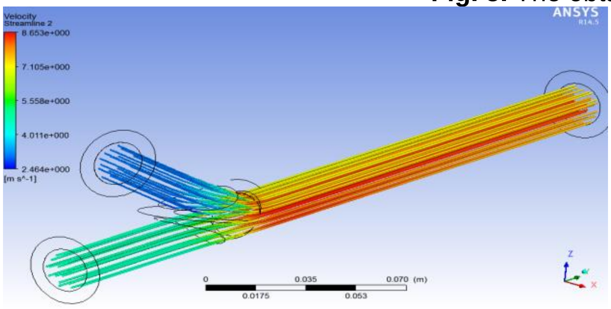


c) Turbulence eddy dissipation

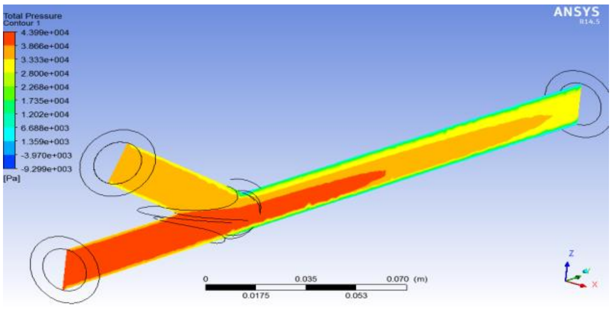


d) Turbulence kinetic energy

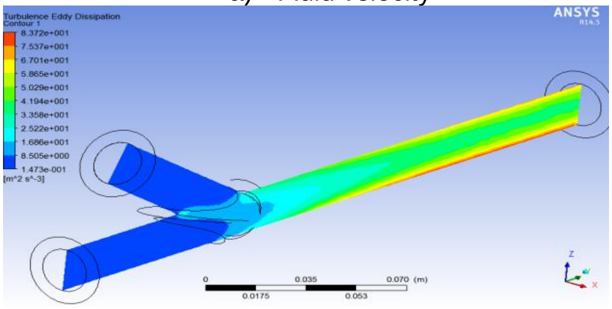
Fig. 5. The obtained results for case 2



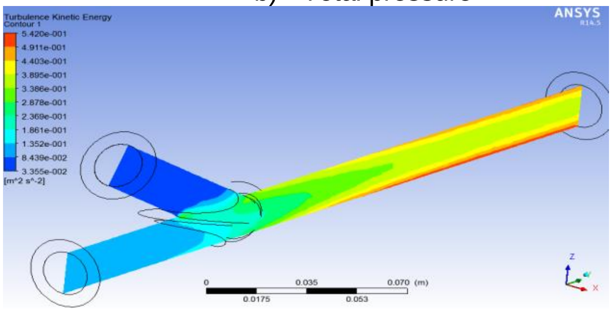
a) Fluid velocity



b) Total pressure

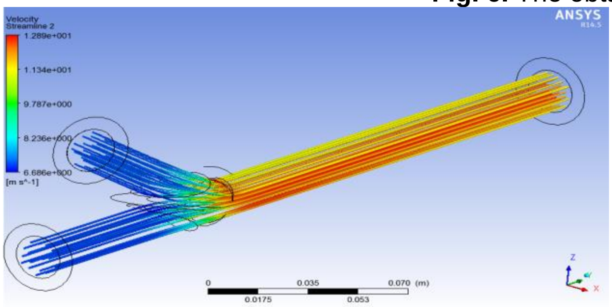


c) Turbulence eddy dissipation

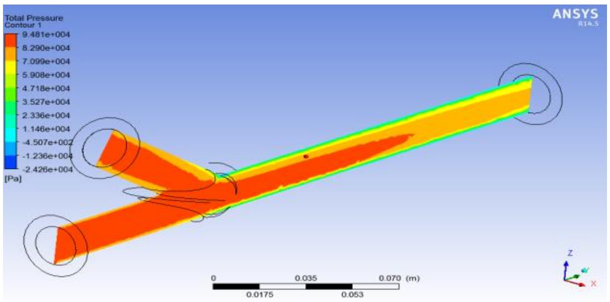


d) Turbulence kinetic energy

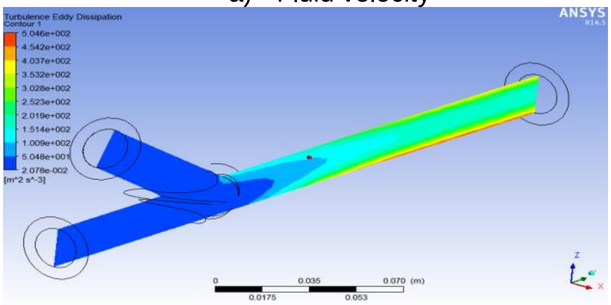
Fig. 6. The obtained results for case 3



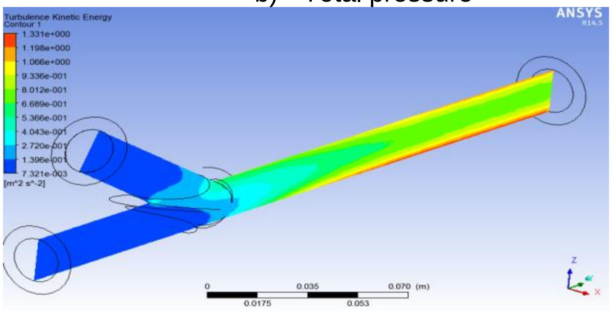
a) Fluid velocity



b) Total pressure



c) Turbulence eddy dissipation



d) Turbulence kinetic energy

Fig. 7. The obtained results for case 4

Table 4: The obtained result values

	Case 1	Case 2	Case 3	Case 4
Fluid velocity (m/s)	8.67	13.31	8.65	12.89
Total pressure (Pa)	44530	100000	43990	94810
Turbulence eddy dissipation (m2/s3)	256.2	1696	83.72	504.6
Turbulence kinetic energy (m2/s2)	0.68	1.78	0.54	1.33

The obtained results show the flow pattern of the working fluid inside the pipe, according to the declared inlet values. A laminar flow model can be observed in the area of the two entrances but becomes turbulent after the fluid flowing from the two intakes makes the mixture.
The values obtained are specific to each case, depending on the declared initial calculation data.

5. Conclusions

Flow aspects of the working fluid through the circular pipes have been presented in this paper, highlighting the laminar and turbulent regime as well as the conditions in which they occur during the operation of a hydrostatic drive system.
For example, a numerical analysis was carried out on the virtual model of a pipeline that is crossed by a hydraulic fluid with the properties of a mineral oil.
The results show the values of flow velocity, total pressure and turbulence recorded at the analysed fluid region for each analysed case.

References

[1] Axinti, S., and F. D. Scheaua. *Introduction to industrial hydraulics/ Introducere în hidraulica industrială.* ISBN 978-606-696-032-8, Galati, Editura Galati University Press, 2015.
[2] Axinti, G., and A. S. Axinti. *Fluid Power Systems/ Acţionări hidraulice şi pneumatice.* Vol I-V. Chişinău, Editura Tehnica-Info, 2008-2012.
[3] Vasilescu, Al. A.. *Fluid Mechanics/ Mecanica fluidelor*. Ministerul Educaţiei şi Învăţământului, Universitatea din Galaţi, Galaţi, 1979.