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FLUID FLOW ASPECTS REGARDING TURBULENT REGIME AS A CHARACTERISTIC OF FLUIDIC SYSTEMS

Abstract: *There are obvious many applications in the industry field that use fluidic systems in order to drive different specific equipments and machines. That is why the research activities aimed for analyzing and studying the involved phenomenon at the level of these force applications are justified. In order to do this is needed to start with the flow pattern used inside the working circuits of these applications. This paper presents some aspects of the turbulent flow model that predominates within fluidic actuation systems, with focus mainly on the values of specific parameters involved in the flow process with a certain velocity value working at high pressure values.*

Key words: *fluid flow, fluidic actuation, turbulent regime, numerical analysis.*

1. INTRODUCTION

The basic property of fluids is based on the attraction or link forces much lower in value than those found in solid bodies that allow them to be flexible for free movements.

Low-value external forces are transposed into large deformations on the fluid so that it has adherence to its own volume and requires no special effort to be moved by sliding.

Based on the principles of fluid mechanics to show the typology of the fluid environment, it is considered the incompressibility property at external forces applied, while being homogeneous and isotropic.

In order to study the fluid state of movement, it is considered an infinitely small volume of fluid that has the ability to preserve the initial characteristics of the continuous fluid medium.

A fluid volume containing a large number of molecules is chosen, while their own movement is neglected, over which infinitesimal calculus can be applied.

The specific values measured over time containing the initial moment are attached to the considered fluid particle represented by the displacement velocity, pressure, fluid density, or temperature.

Based on the principle of homogeneity and isotropy of the fluid used in study it can be considered that the relationships established for the fluid particle are valid for the entire fluid volume.

The general principle of fluid continuity shows that at one point $A(x,y,z)$ at time *t*, the values for: [2]

$$\begin{aligned} \rho &= \rho(A,t) \\ p &= p(A,t) \\ v &= v(A,t) \\ T &= T(A,t) \end{aligned} \tag{1}$$

are continuous throughout the analyzed fluid volume.

Within a fluid stream there may also be situations in which these functions are not continuous, for example on certain surfaces where more physical quantities are discontinued at the same time.

If a pressure value is considered as an example, it can be assumed that for the shock waves applied to the fluid on a surface and the separation surface between two immiscible liquids there is a discontinuity of the pressure values.

Because of the complex phenomena involving fluid flow, it has become necessary to define certain simplified fluid models that will ensure the construction of a characteristic model valid for the entire fluid volume.

Thus, the Euler fluid model describing a non-viscous ideal fluid, the Newton model, for a viscous fluid and the Pascal model for an incompressible fluid for which the volume of fluid mass does not change when changing the pressure values are defined.

In fact, the fluid is compressible (it changes its volume under the action of pressure forces) and exhibits its own viscosity, which determines the flow resistance.

The general theoretical principles related to the fluid flow model are presented, focusing on the specific parameters that determine the turbulent flow model, as the most common model in the practice of fluid flows.[3]

2. EFFORTS ACTING ON FLUIDS

For a system with a working fluid, it is considered that the fluid environment is moving in order to ensure the functionality of the system in which it works.

The characteristics of the fluid contained within the system at a particular time *(t)* are represented by the volume *(V)* and the surface *(S)*.

The main forces externally acting on the fluid are mass type due to external gravitational, magnetic or electric forces acting directly on the fluid particles having a value proportional to the fluid mass.

The forces acting both from the outside and from the inside *(fm)* acting on the working fluid are dependent on the fluid particle position vector, the particle displacement velocity *(v)*, and time *(t)*: [2]

$$\vec{f}_m = \vec{f}_m(\vec{r},\vec{v},t)\,;\, \rho = \rho(\vec{r},t) \tag{2}$$

The mass forces resultant acting on the elementary fluid particle is given by: [2]

$$d\vec{F}_m = \rho \vec{f}_m dV \tag{3}$$

Also, on the contact between the fluid and the pipe walls in which it flows, there are external and internal surface forces.

The contact between the fluid and the pipe walls has the role of developing surface molecular forces. Inner surface forces are the result of the surface action of the fluid particles in contact with the pipe wall.

The external and internal mass forces, as well as the external and internal surface forces acting on the fluid, are subjected to the equal action and reaction principle of the elementary fluid particles.

Under normal conditions within a fluid, only compressive stresses can be recorded because the traction forces cannot be supported due to the fluidity property.

In the flow of real fluids, the compressive stress in the normal direction has two components in two directions, namely the normal direction and the tangential direction.

The component in the normal direction is due to pressure and viscosity values, and the component in the tangential direction is due only to the viscosity values of the fluid.

3. METHODS USED FOR KINEMATIC FLUID FLOW

In order to study the kinematic movement of fluids, the forces that determine the flow and the transformations in the energy field are not considered, but the geometric properties of fluid flow are taken into account.

The study consists in determining the trajectory, velocity and acceleration values for the fluid particles.

The fluid is considered a continuous medium, the flow being characterized by hydraulic parameters as continuous and time-dependent functions of space.

The totality of the elementary particles is the mass of fluid, and the movement of a single particle can be assimilated to the entire fluid mass.

As a first study method of fluid movement is the Lagrange method which reports the fluid particle movement to an axle system *(OXYZ)* considered to be fixed.

The initial position of fluid particle at the time (t) relative to the initial time is reported.

The relations describing the trajectory of the fluid particle are as follows: [2]

$$\begin{aligned} x &= x\left(x_0, y_0, z_0, t\right) \\ y &= y\left(x_0, y_0, z_0, t\right) \\ z &= z\left(x_0, y_0, z_0, t\right) \end{aligned} \tag{4}$$

For velocity values the relationships are as follows: [2]

$$u = \frac{\partial x}{\partial t}, v = \frac{\partial y}{\partial t}, \omega = \frac{\partial z}{\partial t} \tag{5}$$

And for the acceleration values relationships have the following form: [2]

$$\begin{aligned} a_x &= \frac{\partial u}{\partial t} = \frac{\partial^2 x}{\partial t^2} \\ a_y &= \frac{\partial v}{\partial t} = \frac{\partial^2 y}{\partial t^2} \\ a_z &= \frac{\partial \omega}{\partial t} = \frac{\partial^2 z}{\partial t^2} \end{aligned} \tag{6}$$

Lagrange variables represented by the initial coordinates show the position of a fluid particle at a particular point in time.

One of the most used methods for the kinematic study of fluid flow is represented by Euler method, which studies the velocity field in the space points occupied by the moving fluid particles as well as the change of the velocity values over time.

For the velocity values field, the relationships are as follows: [2]

$$\begin{aligned} u &= u\left(x, y, z, t\right) \\ v &= v\left(x, y, z, t\right) \\ \omega &= \omega\left(x, y, z, t\right) \end{aligned} \tag{7}$$

where $\left(x, y, z\right)$ are the coordinates of the space points.

With the Euler method it is necessary to know all the velocity values at all points of the space and for each time.

The trajectory of a particle can be determined based on the position, velocity and acceleration values starting from the particle coordinates at the initial time: [2]

$$u = \frac{dx}{dt}, v = \frac{dy}{dt}, \omega = \frac{dz}{dt} \tag{8}$$

Through integration results: [2]

$$\begin{aligned} x &= x\left(x_0, y_0, z_0, t\right) \\ y &= y\left(x_0, y_0, z_0, t\right) \\ z &= z\left(x_0, y_0, z_0, t\right) \end{aligned} \tag{9}$$

It is intended to determine the particle acceleration field that has to consider the coordinate and time functions: [2]

$$du = \frac{\partial u}{\partial t} dt + \frac{\partial u}{\partial x} dx + \frac{\partial u}{\partial y} dy + \frac{\partial u}{\partial z} dz \tag{10}$$

Thus, the fluid particle acceleration relationships are obtained: [2]

$$\begin{aligned} a_x &= \frac{du}{dt} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \omega\frac{\partial u}{\partial z} \\ a_y &= \frac{dv}{dt} = \frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \omega\frac{\partial v}{\partial z} \\ a_z &= \frac{d\omega}{dt} = \frac{\partial \omega}{\partial t} + u\frac{\partial \omega}{\partial x} + v\frac{\partial \omega}{\partial y} + \omega\frac{\partial \omega}{\partial z} \end{aligned} \tag{11}$$

4. ASPECTS OF FLUID FLOW TURBULENT REGIME

If reference is made to the flow of working fluid in a circular pressure pipe, in the case of laminar flow, the velocity value is kept constant over time relative to the average velocity in the fluid flow section.

In the event of changes in the flow section or different devices interposed into the flow network it is observed that the laminar flow regime gradually turns into turbulent flow characterized by the momentous change in the velocity values of the fluid.

The turbulent flow of the working fluid has the property of preserving the character over time, which means that although the values for the movement velocity of the fluid particles change over time, average velocity values that are constant over time are retained.

In Figure 1 there are presented the changing values for the fluid velocity in time where (v) represents the instantaneous value of the fluid velocity, $(\bar{v})$ mean medium velocity values, and (v') represents the pulse values for fluid velocity.

The relationship between the fluid velocity values is as follows: [4]

$$\bar{v}(x,y,z) = \frac{1}{T}\int_0^T v(t)\,dt \tag{12}$$

The pulsatory velocity rate is presented as: [4]

$$v'(x,y,z,t) = v(x,y,z,t) - \bar{v}(x,y,z) \tag{13}$$

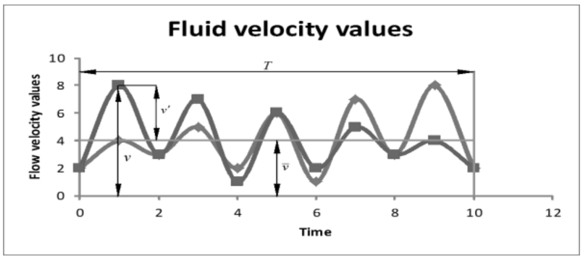

Fig. 1. Fluid flow velocity values change in time

The complexity of the turbulent flow of fluids has led to many studies that have materialized in three basic theories:

- The theory of blend length, or impulse transport (PRANDTL), which considers a constant impulse value over the entire length of the fluid mixture;
- Swirl transport theory (TAYLOR), which assumes that the velocity rotor remains constant;
- The theory of turbulence (von KARMAN), which is based on similarity and considers the turbulent current stream as not dependent on viscosity and the turbulence is similar throughout the length of the fluid flow, being different in lengths and time period.

5. TURBULENT FLUID FLOW INSIDE CIRCULAR DUCTS

It is known that the fluid flow inside the circular ducts is mainly influenced by the medium velocity field over time and the pressure gradient.

If reference is made to the inner profile of the pipeline, it can be established the difference between the typology of the inner surface of the pipes through which the fluid circulates with regard to roughness.

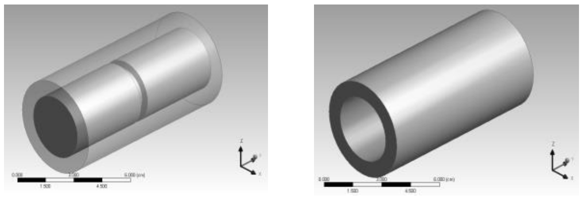

Fig. 2. Circular pipe and fluid region model **Error! Reference source not found.**

The circular pipe model as shown in figure 2 presents a smooth or a rough inner surface that can affect the fluid flow regime.

A rusty surface of the pipeline has a significant influence on the change in flow parameters of the fluid, determining the occurrence or amplification of turbulent motion inside the pipe.

The following types of pipe flow regime can be distinguished: [5]

- laminar regime:

$$\mathrm{Re} < \mathrm{Re}_{cr} = 2320 \tag{14}$$

$$\lambda = \frac{64}{\mathrm{Re}} \tag{15}$$

- transition from laminar to turbulent:

$$\mathrm{Re} \in (2320 - 3400) \tag{16}$$

- turbulent flow regime:

$$\mathrm{Re} > \mathrm{Re}_{cr} \tag{17}$$

In a low-thickness layer positioned just near the pipeline wall, the mixture of fluid particles is slower, the velocity gradient is high, and the stresses are due to the viscosity of the fluid.

This fluid area is considered to be a laminar flow substrate.

The thickness of the laminar substrate is given by: [5]

$$\delta_l = \frac{32D}{\mathrm{Re}\sqrt{\lambda}} > \bar{\Delta} \tag{18}$$

where $(\bar{\Delta})$ is the average roughness of the pipe.

For pipelines with a considerable value for the roughness of the inner wall, the following two situations can be distinguished in relation to the thickness of the laminar substrate near the pipe wall within the turbulent fluid stream:

- turbulent flow through semi-rough pipes when:

$$\delta_l \cong \bar{\Delta} \tag{19}$$

- turbulent regime through rough pipelines:

$$\delta_l < \bar{\Delta} \tag{20}$$

Together with flow velocity values and geometric dimensions of the pipeline through which the flow takes place in the calculation of the distributed load loss, the parameter (λ) appears being directly dependent on the Re number which determines the flow regime type.

It is presented the dependence of the load loss coefficient (λ) to the Re number depending on the situations presented regarding the corresponding flow regime.

In figure 3 is presented the diagram for load loss coefficient for the laminar flow regime with Re number up to 2320.

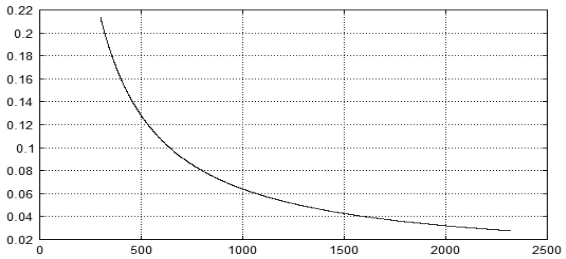

Fig. 3. Values for (λ) function of Re number (2320)

Figure 4 presents the diagram for the load loss coefficient for the transition flow regime with Re number within the range of (2320-3400).

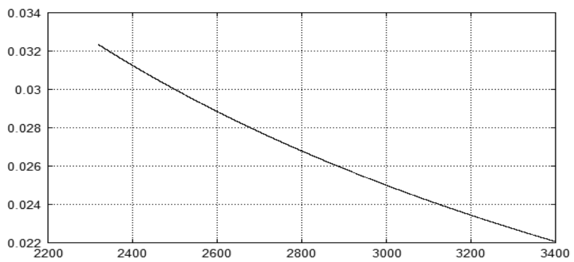

Fig. 4. Values for (λ) function of Re number (2320-3400)

Figure 5 presents the diagram for the load loss coefficient for turbulent flow regime related to Re number within the range of (4000-10exp5).

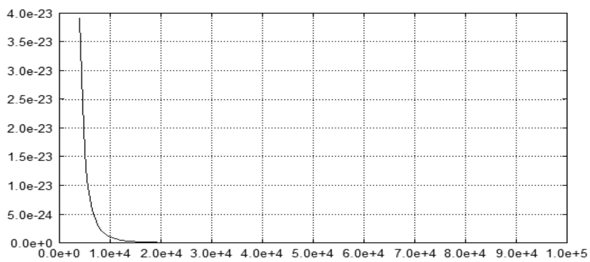

Fig. 5. Values for (λ) function of Re number (4000-10exp5)

6. CONCLUSIONS

Due to the fact that the working fluid within a hydrostatic actuation system is the support through which the forces between the active components of the working circuit are transmitted, both the properties of the fluid used and the flow regime inside the piping must be known.

The fluid flow phenomena that occur when circulating through pipes and various circuit devices are always accompanied by energy losses (pressure drops) that greatly influence the energy transmission process.

The losses must be reduced in order to achieve an improvement in the flow by modifying certain parameters related to the flow sections and the flow regime.

The turbulent flow regime is a dissipative energy model. When flowing through circular ducts, the laminar flow regime becomes instantly turbulent and the boundary layer becomes turbulent, his thickness increases towards the pipe center.

The turbulent flow regime is characterized by Reynolds number, Re>2320 (2000 for mineral oil) and the load loss coefficient, (λ), being dependent on the Re number, the roughness of the pipe walls, the working agent temperature and the hydraulic track geometry.

Load loss coefficient is the parameter that determines the magnitude of losses in the linear fluid flow phenomenon.

Due to the adhesion of the fluid particles to the pipe walls, the fluid velocity values are changed until the flow stabilization length is reached. This leads to fluid flow with load loss (pressure drop) as a result of the accumulated inertial forces and fluid viscosity forces.

Pressure drops within a circuit have to be defeated by the system's hydrostatic unit and are combined with the pressure values required in order to operate the working body.

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