Fişa suspiciunii de plagiat / Sheet of plagiarism's suspicion	**Indexat la: 91/06**

Opera suspicionată (OS)	**Opera autentică (OA)**
Suspicious work	**Authentic work**

OS	TOPLICEANU. L. The phenomenon of cavitation in hydraulic power system.*Modelling and Optimization in the Machines Building Field (MOCM)*, vol.1 no.13, 2007, p.291-294.
OA	Toivula, T. On cavitation in fluid power. In: *Proc. of 1st FPNI-PhD Symp.*, 2000, Hamburg, p. 371-382.

Incidenţa minimă a suspiciunii / Minimum incidence of suspicion	
p.291:14 – p.292:10	p.373:07 – p.374:10
p.292:Fig.1	p.373:Figure 2
p.292:11 – p.293:02	p.374:14 – p.375:14
p.293:Fig.2	p.376:Figure 4

THE PHENOMENON OF CAVITATION IN HYDRAULIC POWER SYSTEM

LILIANA TOPLICEANU

University of Bacau

Abstract: Cavitation is a complex phenomenon that can affect fluid power system and components in various ways. Cavitation normally occurs when liquid at constant temperature is subjected to vapor pressure. In fluid power applications the evaporation pressure is reached when flow velocity is increased sufficiently. One of the consequences of cavitation is the erosion, the mechanical degradation of the solid materials. The direct detection of cavitation is often impossible due to the complicated construction of fluid power components. Cavitation erosion mechanisms are described and are presented methods for cavitation detection.

Keywords: cavitation, erosion, pressure, detection

1. INTRODUCTION

An undesired phenomenon in hydraulic system is cavitation. Cavitation is a term used to describe a process, which includes nucleation, growth and implosion of vapor or gas filled cavities. The cavitation takes place when the static pressure in the fluid decreases to a level below the ambient pressure that determine thus forming *vacuum holes* in the fluid. When the pressure increases these *vacuum holes* implode. During this implosion the pressure increases tremendously and the temperature rises to about 1100 degrees Celsius. The high pressure in combination with the high temperature causes a lot of damage to the hydraulic components.

2. CAVITATION IN HYDRAULIC SYSTEM

The sensible points of a fluid power system for appearance of cavitation phenomenon are the strangles in circuit, like the orifices. Flow rate through an orifice is affected by a number of factors. The flow rate is a function of pressure difference across the orifice. Also the geometry of an orifice has a significant effect on the flow characteristics. Diameter and length of an orifice, as well as the shape of inlet corner determines the flow path of the liquid. The behavior of oil is dependent on its properties, including viscosity, density, and additives.

When the pressure difference across an orifice is increased sufficiently, cavitation occurs at the exit flow. Cavitation starts when the inlet corner of an orifice is sufficiently sharp and the flow detaches from the orifice walls. At this stage a vapor region is formed inside the orifice. When the downstream pressure behind the orifice is reduced sufficiently, the cavitation intensifies and the vapor region is extended beyond the exit of orifice.

The pressure distribution at steady state flow in ideal orifice is presented in Figure 1. Due to increased velocity of flow in constricted vena, dynamic pressure head is increased and hence static pressure head is decreased. When static pressure in is decreased to the evaporation pressure of a liquid, cavitation starts to occur. Cavities traveling along the flow collapse when they enter to higher pressure region of flow. When downstream pressure is decreased further the cavitating region becomes longer. The faster the pressure recovery behind the orifice is the more violent are cavity implosions.

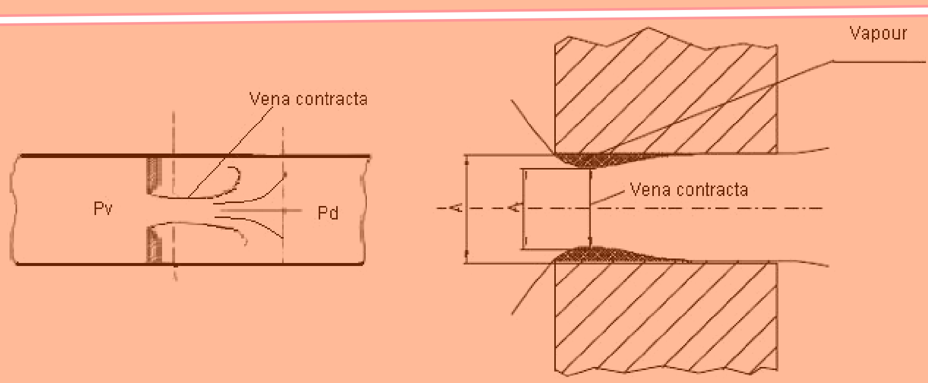

Fig. 1

When cavitation is intensive enough the flow rate through an orifice does not increase when the downstream pressure is decreased. This phenomenon is typically referred as "saturation" or "choking". The degree of cavitation can be estimated with the aid of a non-dimensional parameter named cavitation number, *K*.

$$K = \frac{2 \cdot (p_d - p_v)}{\rho \cdot v^2} \tag{1}$$

The numerator in the equation above corresponds to the static pressure, which resists cavitation, and denominator corresponds to the dynamic pressure, which promotes cavitation. When cavitation starts the cavitation number is called incipient or critical cavitation number. Usually the critical cavitation number for orifices is between 0, 2 and 1, 5 [4].

Flow rate for turbulent flow through an orifice is typically calculated using the following equation

$$Q = C_q \cdot A \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}} \tag{2}$$

where: C_q = flow coefficient
A = cross-sectional area of flow path
Δp = pressure difference across the orifice
ρ = density of liquid

In practice, when calculating the flow through a valve, a problem arises when determining the flow coefficient. The flow coefficient is dependent on the geometry of orifice and the properties of the liquid. In a simple model to calculate the flow coefficient (Cq) for cavitating orifice flow [3], a constant value of coefficient flow is used for noncavitating flow and for cavitating flow, Cq is calculated with the formula:

$$C_{qcav} = C_c \cdot \sqrt{K_s} \quad \text{where} \quad K_S = \frac{p_u - p_v}{p_u - p_d} \tag{3}$$

As shown in Figure 1, when cavitation occurs, the vapour region occupies a fraction of the orifice cross-sectional area (A) and the flow passes through vena contracta (Ac). The contraction coefficient C_c represents the ratio of areas Ac and A. C_c is a strongly geometry-dependent parameter.

$$A_c = C_c \cdot A_c \tag{4}$$

For cavitation free flow at sharp edged orifices ($l / D \approx 2$) values for the flow coefficient and contraction coefficient are 0,84 and 0,61, respectively.

4. CAVITATION EROSION

Cavitation erosion can be formed when cavity implosions are violent enough and they take place near enough to the solid material. Cavitation erosion can be identified from a specific rough mark in surfaces of component flow paths. Even though the great deal of research the actual mechanism of cavitation erosion is still not fully clear. At present it is considered that there are two possible mechanisms to cause cavitation erosion. When a cavity collapses within the body of liquid, the collapse is symmetrical. The symmetrical collapse of a cavity emits a shock wave to the surrounding liquid. When a cavity is in contact with or very close to the solid boundary, the collapse is asymmetrical. In asymmetrical collapse the cavity is perturbed from the side away from the solid boundary and finally the fluid is penetrating through the cavity and a micro-jet is formed (Figure 2).

However, it has been stated that each of these mechanisms has features that do not give a full explanation to the observed cavitation erosion phenomena. The shock wave is attenuated too rapidly and the radius of the cavity micro-jet is too small to produce the degree of the overall cavitation erosion. The degree of cavitation erosion is affected by various factors. The intensity of cavitation determines the load, which is subjected to a solid surface. Geometry of flow paths, pressure distribution in a system, and properties of fluid, including cleanliness level of the fluid determine the intensity of cavitation. When cavitation exists, the formed cavitation erosion is dependent on material properties like hardness, work hardening capability, and grain size. In traveling cavitation, where cavities travel with stream flow, cavitation erosion is not formed in the place where cavitation incepts, but further downstream. This often leads to wrong conclusions when the reasons for cavitation are discussed and preventive actions are often targeted to wrong locations.

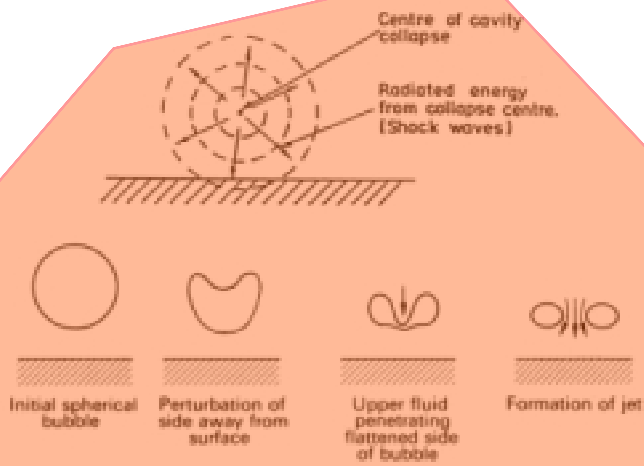

Fig. 2. The shock-wave mechanism and micro-jet mechanism of cavitation erosion.

5. DETECTION OF CAVITATION

Detection of cavitation can be done directly only by verifying the existence of cavities. Direct detection is possible by observing visually the population of developed cavities in flow passages. However, fluid power components encompass usually complicated constructions and cavitation can occur in various locations where the access for visualization instruments is limited. Due to restrictions of direct detection of cavities, various indirect methods can be used. Indirect measurement methods are especially useful if the measurement data from non- cavitating circumstances is available. Cavitation generates typically high frequent vibration from which the existence of cavitation can be recognized.

5.1 Monitoring of Steady-State Flow Behavior

The presence of cavitation can be detected by monitoring steady-state flow behavior of a fluid power component. When pressure downstream from a valve is reduced sufficiently, flow rate does not increase with the increasing pressure drop across the valve. By measuring the characteristic curve of a valve, a cavitating range can be determined. In addition, in the case of pumps, cavitation in suction line reduces the efficiency of the pump. When pressure is reduced in the suction line, pump chambers do not fill completely due to air-release in suction line. Measurement of the flow rate on pump outlet reveals the reduction in pump flow and hence cavitation.

5.2 High-Speed Monitoring of Pressure and Vibrations

When detecting cavitation indirectly, the question is typically about measuring the shock waves induced by cavity implosions. Cavity inception is at first seen in very high frequencies, and therefore very fast transducers are needed. Shock waves can be recorded in the cavitating fluid with high-speed pressure transducers. The propagation of shock waves continues from fluid to the surrounding component body and measurement of the acceleration of the component surface reveals the presence of cavitation.

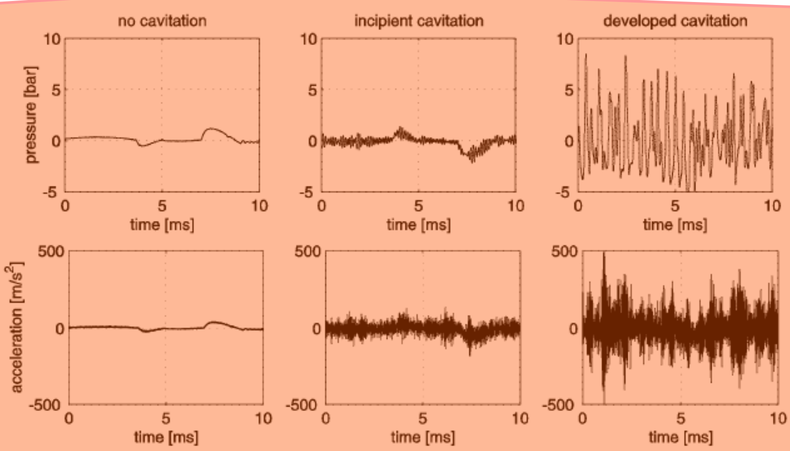

Fig. 3. Cavitation intensifies from left to right. [3]

In the left, no cavitation is present and only pump fluctuations can be seen. In the second figure, cavitation has just incepted and when cavitation has developed extensively (in the right), the pressure peaks get higher. In the Figure 3, also the vibration (acceleration) of the test block surface is presented. The difficulty in acceleration measurements is the isolation of disturbing vibration sources of the component

6. CONCLUSIONS

The fluid power systems are affected by cavitation in the same manner like pumps, impellers, turbines and one of the important effects is the erosion of the materials. Because of the complicate construction of the hydraulic elements is difficult to use instruments for visualization of the erosion damages. In the case of that can be utilized indirect methods for revealing the dimension of the cavitation, methods like monitoring of steady-state flow behavior, the monitoring of pressure and vibration, monitoring of acoustic pressure, emission or flow visualization.

REFERENCES

[1] Anton, I. *Cavitatia, vol I,II* Editura Academiei Române, 1984, 1985.

[2] Bologa, O. *Aspects of cavitation studied in the hydrodynamic cavitation tribomodels*, The Annals of University “Dunărea De Jos” of Galati, Fascicle VIII, 2002.

[3] Koivula, T., Ellman, A., Vilenius, M**.** *Cavitation Erosion - The Effect of Oil Type and Water-in-Oil-Quantity*. The Sixth International Conference on Fluid Power SICFP’99, Tampere Finland 1999.

[4] Lamb, W. S**.,** *Cavitation and aeration in hydraulic systems*. Bedfordshire, UK. BHRGroup, 2001..

[5] Moraru, L. *Cavitaţia acustică*”, Editura Oficiului de Informare Documentară pentru Industrie, Cercetare, Management, Bucureşti, 2002.