THE CHARACTERISTICS OF CAVITATING FLOW AND THE RESULTS OF NOISE INVESTIGATIONS

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Received: March 29, 1984

Summary

This paper presents the most fundamental laws of cavitating flows complemented with the results of noise investigations. It deals also with estimating the intensity of cavitation in places not accessible to visual observations and — in the case of pumps — with the definition of critical suction values.

Introduction

To find the general laws of cavitating flow and to determine the relation of the hydraulic character and the properties of erosion have been the most intensive research fields of the last decades. The development of measuring techniques, the progress of picture and sound recording methods and signal technique contributed to achieve new results. This progress is a source of new results by itself, too.

The broadest scope of investigations consisted of erosion researches helping the selection of materials to use in fluid machines, but in finding the regularities of cavitation phenomena noise detecting methods had also an important role, since they render possible to detect cavitation, to measure its intensity and to give its adequate data in places not accessible to visual observation.

Several outstanding general reports deal with the circumstances of cavitation appearance and with the characteristics, regularities and environmental impacts of cavitating flows (e.g. [1], [2], [3]).

A feature of cavitation investigations in the last decades was that international cooperations came into being for the research of partial fields.

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These have significantly contributed to the mutual control of the research results of cavitation phenomena and to the formulation of its laws.

The Department of Hydraulic Machines of the T. U. Budapest — by building a hydrodynamic tunnel — (Fig. 1. [4]) joined the cavitation

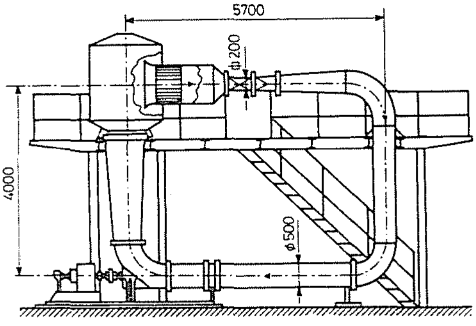

Fig. 1. Hydrodynamic tunnel of the Department of Hydraulic Machines (Technical University Budapest)

investigation programme in 1959. The aim of this paper is to present the results of the authors' investigation on cavitating flow, erosion and noise and to compare their mutual relation with the results of other researchers.

General characterization of cavitating flows

Extent of cavitation and cavitation number

It is known that the state of cavitation can be written by characteristics of the cavitation state. Such state characteristics are: cavitation number, the length of cavitation zone, the area of cavitation zone, noise level (sound pressure level or acceleration level), material quantity eroded during a time unit (intensity of cavitation erosion) etc.

a. Cavitation number

To characterize the cavitating flow in hydrodynamic systems the use of Thoma's cavitation number is generally accepted:

$$\sigma = \frac{p_r - p_v}{(\rho/2)\, v_r^2}\,.$$

p_r is the reference pressure, being the static pressure at an unequivocally defined point or cross-section in the undisturbed flow. v_r is the reference velocity, i.e. the velocity of the undisturbed flow. p_v is the vapour pressure belonging to the given temperature of the fluid. ρ is the density of the fluid. It is required of the reference point and/or cross section, that there the pressure should be measurable and the velocity should also be measurable or could be calculated from the flow rate. The reference point is generally marked out upstream of the body causing cavitation. It is advantageous to do so as the cavitation does not disturb the flow in the reference point. The disadvantage of this method is that the cavitation number is determined by pressure difference of flow areas where there is no cavitation. Such a so-called first type cavitation number serves in the first place to judge the appearance of cavitation. In the case of pumps such cavitation numbers are:

$$\sigma_p = \frac{\mathrm{NPSH} - D_1/2}{H_{\mathrm{opt}}} \qquad \text{and} \qquad \sigma^* = \frac{H_{\mathrm{opt}} \cdot \sigma_p}{H};$$

where D_1 is the diameter of the impeller of the first stage, H_{opt} is the head at the best efficiency point of the pump and

$$\mathrm{NPSH} = \frac{p_1 - p_v}{\rho \cdot g} + \frac{c_1^2}{2g}$$

where p_1 and c_1 are pressure and average velocity in the suction branch.

We can mark out the reference point or cross section also downstream the body causing the cavitation. In this case there is a risk that the cavitation alters the reference pressure as compared to the non-cavitating flow. Advantage of this second type cavitation is that the pressure difference defining the cavitation number characterizes the part of the flow where the cavitation phenomenon takes place. The progress of cavitation phenomenon — e.g. the behaviour of the cavitation bubbles, degree of erosion etc. — are significantly influenced by the pressure gradient prevailing in the cavitation zone. Thus for studying the developed cavitation phenomenon the cavitation number of the second type is more suitable.

In a cavitation tunnel with a constant diameter, also the Thoma number takes the role of the second type, since in the downstream cross sections the pressure differs only slightly from the reference pressure.

For investigating cavitation occurring in pumps authors have earlier proposed [5] a cavitation number of the second type:

$$K = \frac{p_2 - p_v}{(\rho/2)\, u_2^2}$$

where p_2 is the pressure at the discharge branch, u_2 is the circumferential velocity of the impeller with D_2 diameter.

One of the aims of this paper is to compare the cavitation phenomena met with in tunnel and in pumps and the elaboration of the analogies found between them. From this point of view it is expedient to call attention to the fact that the change of the angle of attack in pumps is analogous with the change of the form of the body in the tunnel.

b. Extent of cavitation

In the flow, on the closing walls or at the point of minimum pressure of the surface of the body single bubbles appear in case of certain defined flow conditions. These bubbles are taken along by flow and are ceased by it in the range of higher pressures. Expressing flow relations by a suitable cavitation number the value σ_i, characterizing initial cavitation can be determined.

During cavitation processes there are generally differentiated, transient travelling cavitation bubbles and fixed cavitation hollows adhered to bodies that consist of bubble masses with a specific periodic notion.

With a decreasing cavitation number after the appearance of cavitation, bubbles and perhaps also small fixed cavitation hollows appear in flow in zones of low pressure in states following initial cavitation. The main parameters of flow (forces, the Strouhal number of vortices in separating flow, etc.) agree with the values valid in non-cavitating flow, the mechanism of flow is essentially identical with that of non-cavitating flow — cavitation being only an accompanying phenomenon of it. This is the range of physical cavitation. Decreasing the cavitation number below the quite well defined standard or critical value the main parameters of flow, however, change; the regularities of cavitation free flow are not valid anymore: the mechanism of flow is determined by cavitation. From the technical viewpoint only the latter kind of cavitation is important thus cavitation states between critical and blocking states are called "technical" (or strong) cavitation [6]. Flow developing in the surrounding of blocking state is regarded supercavitating flow.

By an increase in the range of minimum pressure a cavitation configuration, the so-called zone, develops with a specific motion and consisting of the aggregation of cavitation bubbles that develop continuously on the body. If a cavitation zone can be observed visually it seems to be of measurable length, width and definite contour.

According to the results of high speed shooting and other measuring (e.g. frequency) methods the cavitation zone is the envelope-curve cavitation hollows periodically separated from the body. The cavitation extent is, in the following, the relative extension of a characteristic and geometrically definite cavitation configuration in hydrodynamic systems i.e.:

$$\lambda = \frac{l_z}{a}$$

where l_z is the characteristic dimension of the cavitation zone (length or width) and a is the characteristic length of the body causing cavitation (e.g. the diameter in case of a cylinder). Its extreme values are $\lambda = 0$ i.e. the case of cavitation free flow and $\lambda = \infty$ the blocking state of the flow system which in principle means a cavitation zone extending to infinity.

The unequivocal correlation between a suitable cavitation number and the extent of cavitation can be regarded as one of the general laws of cavitating flows.

Fig. 2. shows the curve of cavitation extent — cavitation number ($\lambda - \sigma$) of a cylinder in a hydrodynamic tunnel [7].

The results published by EISENBERG [8] are presented in Fig. 3. Similar results were obtained by GRIVNIN, SHLEMENZON and EDEL [9] in their tests with NACA profiles as well as by PAWLAK [10] in determining the relation between

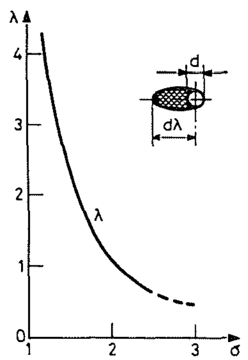

Fig. 2. Dimensionless cavity length (λ) in the function of cavitation number — in case of a cylinder

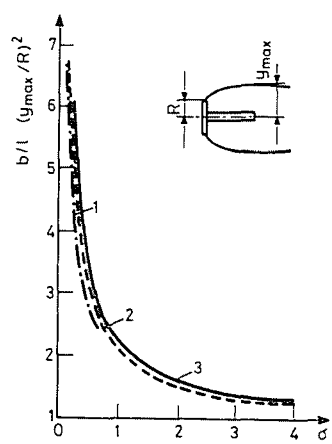

Fig. 3. Relative dimension (b/l) of cavitation zone on basis of theoretical investigations and the change of the relative width $(y_{max}/R)^2$ in the function of cavitation number (σ) [8]; 1. Measurement results, 2. according to jet model, 3. according to RIABOUCHINSKY model

the extent of cavitation developing on an impeller-blade and the cavitation number.

To determine the hyperbolic character of the law of $\lambda - \sigma$ the investigations of NUMACHI [11], SHALNEV [12], STELLER [13], ACOSTA and HOLLENDER [14] (Fig. 4) and KAMIYAMA [15] are basic ones.

According to our own investigations, [5] in case of cavitation occurring on the blades of a semi-open impeller pump the relation between the cavitation extent and various cavitation numbers is shown in Figs 5 and 6. It should be

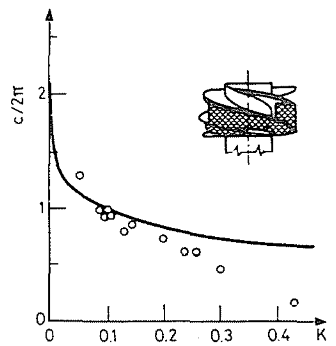

Fig. 4. The length of cavitation zone (C/2 π) as a function of cavitation number (K) according to [14]. The full line shows the result of the theoretical investigations

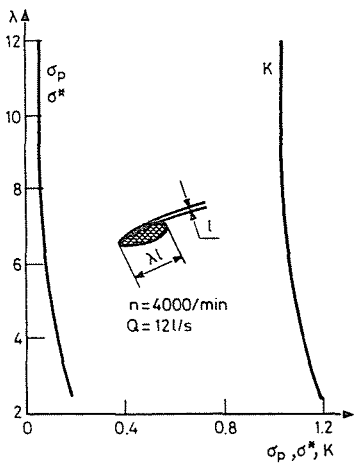

Fig. 5. The relative length (λ) of the cavitation zone appearing on the suction side of the impeller blade in the function of various cavitation numbers (σ_p, σ^*, K)

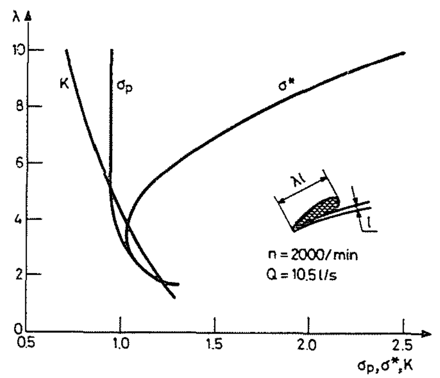

Fig. 6. The relative length of cavitation zone (λ) appearing on the pressure side of the impeller blade in the function of various cavitation numbers (σ_p, σ^*, K)

noted that the length of the cavitation zone is the unequivocal function of the K cavitation number, only the use of number σ^* — although generally accepted — can be regarded, according to experience, as appropriate only for characterizing the extent of suction side cavitation.

c. The kinematic character of the cavity

The most important kinematic character of the cavitating flow is the periodic cavity separation. This kinematic structure gives a satisfactory explanation for the mechanism of erosion and the noise phenomena accompanying the cavitation, respectively.

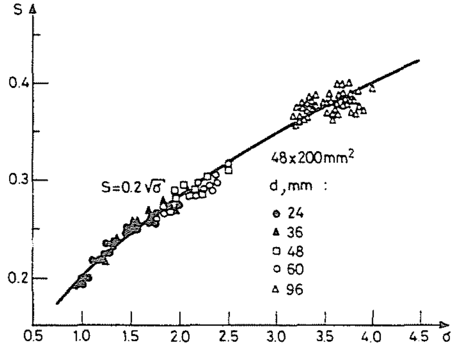

Fig. 7. Strouhal number (S) as a function of cavitation number (σ) in cavitating flow in the case of a cylinder. Dimension of the measuring area: 48×200 mm

The cavitation configuration generated in the flow is of a periodic character. It contains the beginning of the origin of cavity, the process of its development and its separation.

Hollows are composed of vapour bubbles and have well limited contours. Cavitation hollows become unstable in the course of increasing, from the surrounding space of a higher pressure a jet gets into the cavity and demolishes its structure. This phenomenon is periodically repeated. Its law can be described with a relation between Strouhals number* and the corresponding cavitation number [16], [6].

* Strouhal number: $S = fa/v$, where f is the frequency of wakes shedding, a is the characteristic size, v the characteristic flow-velocity.

Some test results for cylinders are given in Fig. 7. The figure does not contain the relation valid for non-cavitating flow. Data concerning the law can be summed up as follows:

YOUNG and HOLL [17] stated a relation between Strouhal and relative cavitation numbers on the basis of examinations by wedge of 15°, 30°, 60° and 90°. The diagram published by the authors also show the value of Strouhal number obtained by experiments with air. (Fig. 8.) YAMAMASU and YOKOMIZO

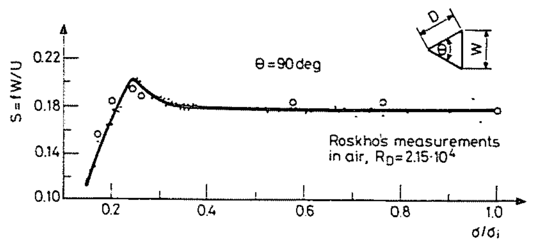

Fig. 8. Strouhal number (*S*) in the function of relative cavitation number (σ/σ_i) in the case of wedge-model according to the tests of YOUNG and HOLL [17]

[18] carried out tests in a measuring area of 15 × 500 mm. KENN and MILTON [19] and KENN [20] resp. give information about tests made with a cylinder of a 31,75 mm dia., in a measuring area of 50,8 mm × 33 mm. They regard the erosion effect of separating vortices as most significant. ALEXANDER [21] carried out cavitation tests by hydrofoils in a tunnel of 170 × 130 mm. He stated that the profil oscillation is caused by repeatedly forming cavities. Measurements were carried out in a velocity range of 2 – 30 m/s while frequency was detected at 3 – 3000 Hz. FURNESS [22] and GUERRERO [23] examined the periodical character of cavitation flow in a narrowing, developed by determined geometrical conditions. The results of these examinations show that cavity separation can be characterized by Strouhal number and separation is caused by jet returning along the surface. In the course of detailed cavitation tests with hydrofoils GRIVNIN, SHLEMENSON and EDEL [24] also published a diagram presenting the Sh – σ relation.

In case of a cylinder, SHALNEV et al. [25] introduced results referring to periodical cavitation hollow separation indicating a relation between Strouhal's and cavitation numbers.

Periodic separation of cavities, as a characteristic part of kinematic structures of a cavitating flow, is the most significant phenomenon of the cavitating flow since, according to investigations, the mechanical effect of pressure waves caused by a relatively high frequency jet impact on the environment is the cause of erosion (macrostructure) while the noise of impact (macrojet which is or can be followed by microjets) is the characteristic of cavitation.

Noise character of the cavitating flow

The basic principle of the noise examination of cavitation originates from the consideration based on the physical content that new noise generators develop in the liquid during the appearance of cavitation. One of them is the oscillation of bubbles that behave like monopoles and radiate in a relatively broad frequency range taking into account the condition determined by environmental conditions and dimensions. Generally the resonance-frequency of a gas bubble in water [26] can be calculated by the relation:

$$fr=\frac{1}{2\pi R}\sqrt{\frac{3\kappa p}{\rho}}$$

where R is the radius of the bubble, κ is the ratio of specific heat, ρ the density of the medium.

Assuming $\kappa=1{,}4$ and $p=1$ bar

$$frD=657\ \text{cm}\cdot\text{Hz}$$

which — regarding bubbles of a great mass and changing diameters — means a broad band radiation. Latest researches, however, refer to the fact that these cavitation bubbles are not radiating continuosly but collapse under the effect of jet impact. In that case the noise of jet-impact (microjet) is a noise picture characteristic of cavitation.

In connection with technical cavitation — according to the preceding — the demolishing of a “fixed” cavitation hollow and its synchronous cutting from the body by a jet entering the cavity (macrojet) deserves special attention. The noise effect of this can be regarded as typical of the characteristic noise spectrum of cavitation.

Pressure waves generated by noise generators superimposed on the noise of the basic wave and deforming the noise of same can be observed well inside the body (by hydrophone), on the surface of the body (by acceleration sensor), away from the body (by microphone). As deafening of microphones from environmental noise is difficult and the dampening effect of air in the space between the surface of the body and the microphone can be significant and it is difficult to get into the machines, whereas any point of the machine body can be looked upon as a radiator, the examination of vibration measured on the body is the most expedient method. It should be noted that the results gained by appropriate application of the methods are congruent.

The test of noise spectra of cavitating flows in range 20 Hz – 20 kHz generally gives a satisfactory result.

The spectrum of a cavitating flow generated by a cylinder inserted into the flow is presented in Fig. 9.

Fig. 10 [27] and Fig. 11 [28] also contain the effects of cavitation of the noise spectrum.

The range $f < 5$ kHz is mainly dominated by a mechanical noise. Above it, however, the practically parallel noise level curves of flows characterized by

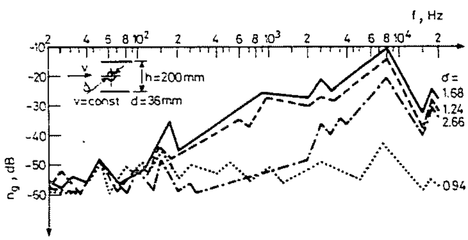

Fig. 9. Noise-level spectra. Acceleration level (n_g) in the function of frequency (f) in the case of cylinder, with various cavitation numbers (σ). The dimension of the measuring area: 48 × 200 mm

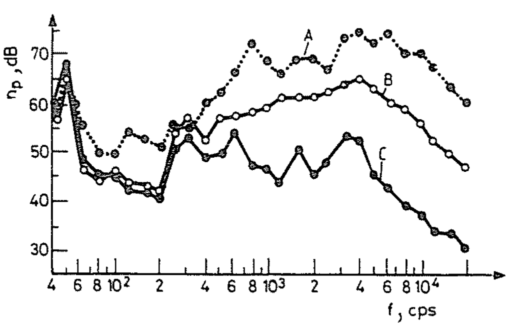

Fig. 10. The change of the sound pressure level (n_p) as a function of frequency (f) in the case of a centrifugal pump at various cavitation conditions according to POKROVSKY and YUDIN [27]

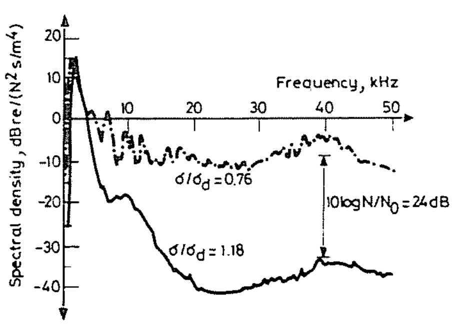

Fig. 11. Frequency spectrum of cavitation noise at two relative cavitation numbers the basis of tests made with a disk in a hydrodynamic tunnel ($d = 8$ mm, $v = 6$ m/s)

different cavitation curves, that is to say the spectra, reflect the typical characters of the flow and so measurements can be made at any discrete frequency to qualify the flow.

In case of a cylinder, Fig. 12. shows the noise level values (at a chosen discrete frequency) plotted against the extent of cavitation [29]. At the same time the figure contains the intensity of the erosion-cavitation number relation, too. The decrease of the cavitation number i.e. the increase of λ, leads from the non-cavitating flow to the state of supercavitation ($\lambda = \infty$).

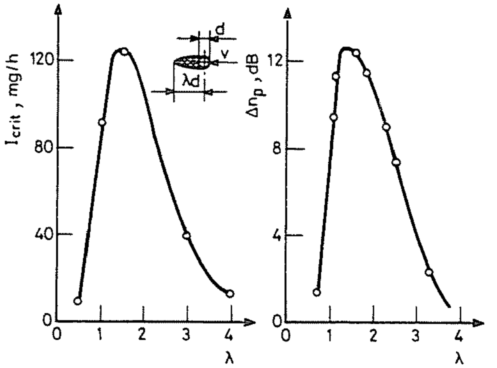

Fig. 12. The changes of the intensity of cavitation erosion (I_{crit}) and the noise level (n_p) in the function of the relative zone length of cavitation (λ) — in case of constant velocity (v) — according to tests made in a hydrodynamic tunnel

Noise level increases — for a time — together with the length of the cavitation zone, then after a peak of intensity the noise level rapidly decreases while the length of cavitation zone increases further. Simultaneously the value of Strouhal number has a decreasing tendency.

The noise level curve is characterized essentially by 3 points and/or ranges: the value of noise level in cavitation-free flow, the noise level of supercavitating flow (where there are neither cavity pulsations nor a cavity collapse) and a narrow range with high intensity lying between the two values. (Noise level curve shows density distribution of intensity; by its form it may be compared with a bell-curve).

If there appear various types of cavitation in one system, there is a difference in the process of their development (e.g. suction-side then pressure-side cavitation on the impeller-blade of a pump or one of these and clearance cavitation etc.). The noise level curves naturally appear as shifted compared to each other, strictly keeping their bell-curve-like character.

The flow pattern developing as a result of the appearance of cavitation — with special regard to the effect of jet deduced from the kinematic structure — characterizes the given state by preferred vibration direction. According to the data of examinations however, the absolute value of accelerations caused by the noise generator and also the spatial direction of the vector change in the development process of cavitation. It follows that the noise level curves obtained in the environment of the appearance of cavitation within reasonable geometrical limits practically always inform correctly about the state of development and intensity of cavitation [30]. With acceleration level measurements carried out in the directions of three datum-lines the directions of vibration and the value of acceleration can be stated according to the following:

$$n_{gr} = 10 \lg (10^{0.1 n_x} + 10^{0.1 n_y} + 10^{0.1 n_z})$$

where n_{gr} is the resultant noise level, n_x, n_y, n_z are acceleration levels measured in certain directions and

$$\varphi_{xy} = \text{arc tg } 10^{0.05 (n_x - n_y)}$$

$$\psi_z = \text{arc tg } 10^{0.05 (n_z - n_e)}$$

and

$$n_e = 10 \lg (10^{0.1 n_x} + 10^{0.1 n_y})$$

Cavitation flow and cavitation erosion

The kinematic structure of cavitating flow and within this the periodic character — the appearance and breakdown of the cavities occurring according to strict laws — the influence exerted on the surrounding by the macro- and micro jets initiating the break down allow the supposition of a direct relation between the character of the flow and the phenomena accompanying the erosion.

In the moment of shearing off of the cavities an essential impulse can be detected in the surrounding of the phenomenon. Measurements, in connection with these were published by YAMAMASU ET ALII [18] (Fig. 13.). The periodic mechanical effect exerted on the surroundings — depending on the character of the flow — results in material fatigue, which after an incubation period, gets into the phase of complete destruction. In the procedure *t* relation of Strouhal number — cavitation number has an essential role because of the periodic character and in determining the number of impacts reaching the surface [31].

The characteristic features of the results gained during noise investigations were deduced from the effects of jet-impacts based on the fact that the intensity of eradiated noise is in direct connection with the erosion intensity. This supposition was convincingly verified by the results of the investigations. In Fig. 12 we show the congruency between the intensity of cavitation erosion and the noise level curve measured at a discrete frequency of a cylinder [32].

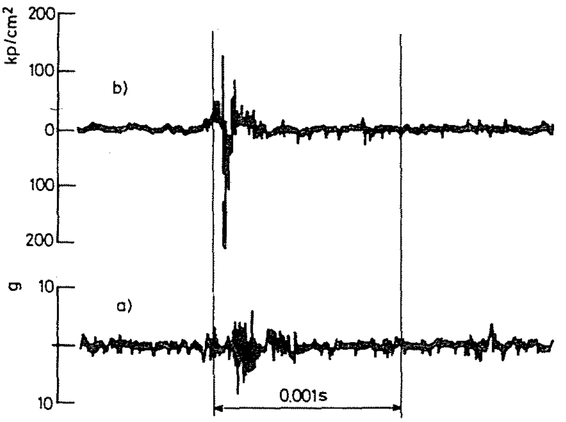

Fig. 13. The changes of acceleration (a) and pressure (b) as a function of time in the case of a cylinder according to the tests of YAMAMASI ET ALII [18]

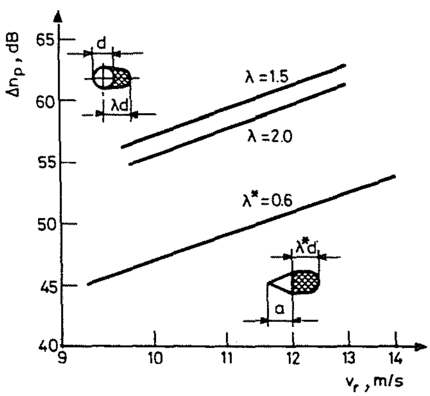

Fig. 14. Noise level (n_p) in the function of reference velocity (v_r) with the related length (λ, λ^*) of cavitation zone as a parameter on the basis of tests made with cylinder and wedge in the hydrodynamic tunnel

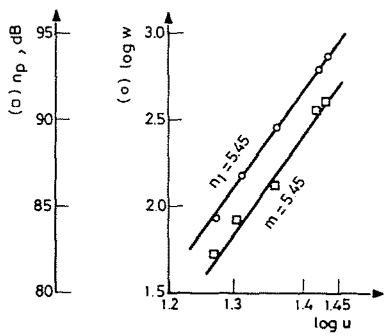

Fig. 15. The changes of the intensity (w) of erosion and the noise level (n_p) in the function of velocity in case of a wedge according to the investigations published in [34]. (u: flow velocity; n_1, m: velocity exponent)

The experiments — excluding the effect of velocity scale number — were realized in case of constant flow rate.

In case of constant cavitation number, i.e. constant cavitation state — the influence exerted on the phenomenon by the velocity can be obtained in changing flow rates and with it static pressures, changing according to rule.

The change of noise level in the function of flow rate in model tests is shown in Fig. 14 [33]. The value of scale number — in case of given cavitation state — can be regarded as constant.

The change of intensity of noise and erosion is shown in Fig. 15 according to the investigations of RAMAMURTHY [34]. The congruency is suitable.

Application of the results of cavitation examinations in the investigation of pumps

Nowadays the results of cavitation research carried out at discrete frequencies can be regarded as widely known. It can be laid down as a fact that the results of the tests made with laboratory models, the measuring methods as

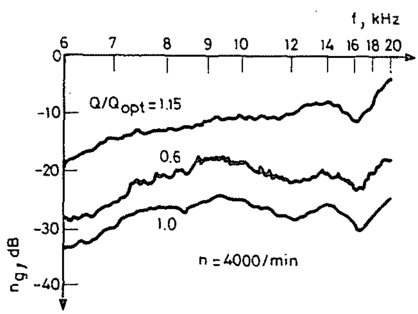

Fig. 16. Acceleration level (n_g) in the function of frequency (f) in case of a centrifugal pump at various relative flow-rates (Q/Q_{opt})

well as conclusions could be adopted to cavitation examination of fluid machines practically without modification.

Noise level spectra presented in Figs 9., 10., 11., 16. and 17. — in agreement with the previous conclusions — enable the examinations to be carried out in discrete frequencies.

For the sake of completeness Fig. 18. presents the noise spectrum of cavitation originating under conditions divergent from the former ones [35]. The lower limit of examinations of discrete frequencies is here $f \cong 1$ kHz.

The flow and cavitation characteristics of a pump at constant speed can be deduced from the so-called noise-level-surface (Fig. 19). The sections of this (pertaining to Q=constant values) are the noise level curves of the suction capacities (Fig. 20), the sections pertaining to K=constant are the noise equivalents of $Q-H$ characteristics pertaining to different suction heads.

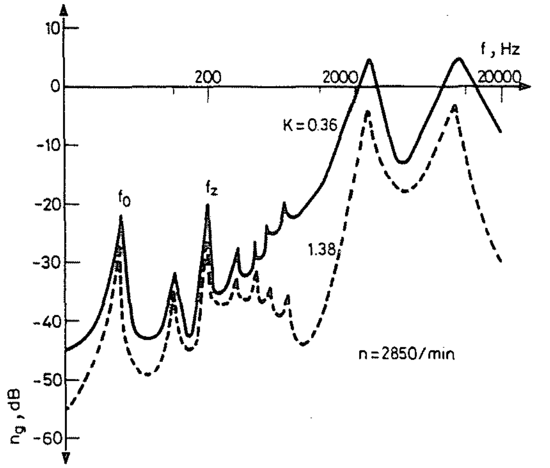

Fig. 17. Frequency-spectra of the running conditions of a centrifugal pump. Noise level (n_g) in the function of frequency with cavitation number (K) as parameter

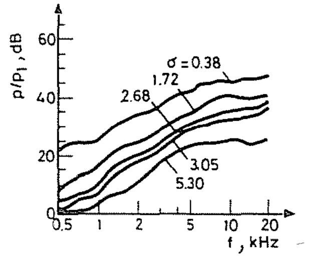

Fig. 18. The density spectrum (p/p_1) of the acoustical power related to the basic noise in the case of various cavitation numbers

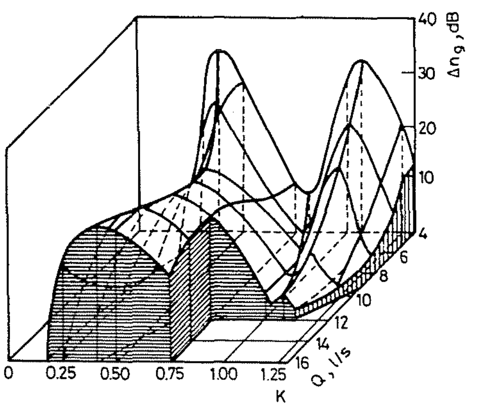

Fig. 19. Surface of the noise level of a pump. The noise level (n_g) in the function of cavitation number (K) and the flow-rate (Q) at constant speed

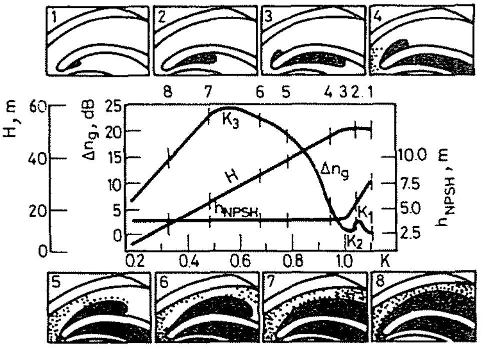

Fig. 20. The change of noise level (n_g), of head and NPSH in the function of cavitation number (K) with sketches of cavitation states

The right side crest of the noise level surface — as seen in Fig. 19 — shows the effect of cavitation appearing on the suction side of the impeller-blade, while the left side crest shows the effect of the pressure side cavitation.

Noise level curves pertaining to each type of cavitation (suction side and pressures side resp.) characterize the procedure of cavitation development with a bell-shaped curve.

The examination of the suction capacity of a pump is an important part of the qualification of machines, which contains problems of practical application, too. Among the qualifying data the so-called critical suction values form the basis of the conventional criteria. In the following we will consider the

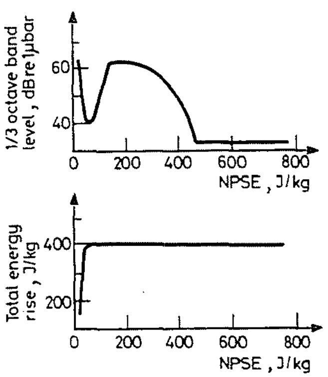

Fig. 21. Suction capacity curve and suction capacity noise level curve from the paper of DEEPROSE ET ALII [36]. (NPSE: Net Positive Suction Energy at pump inlet.)

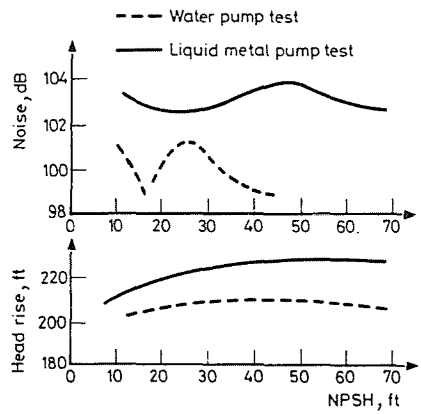

Fig. 22. Suction capacity curve and suction capacity noise level curve for water and potassium according to WOOD ET ALII [37]

suction capacity — noise level curve, i.e. the noise equivalent of the suction capacity curve.

In literature the use of noise level curves of the pumps suction capacity mainly as a function of NPSH, often appears. Fig. 21 shows DEEPROSE's [36], Fig. 22 WOOD's noise level curves [37] with suction capacity curves.

Fig. 23 presents the suction capacity — suction capacity noise level curve of a pump with marking the critical NPSH*.

* $NPSH_{crit}$ is the cavitation reserve belonging to a $(3+k/2)$ percent decrease of the head, where $k=2\pi\, nQ^{1/2}/(gH)^{3/4}$

Figs 24., 25., 26. contain the characteristics, and suction capacity-noise level curves of a pump, respectively.

It can be stated from Fig. 25 that with the decrease in cavitation number, cavitation appears first on the suction side of the impeller blade followed by the pressure side cavitation.

It can be seen from the critical data marked on the noise level curves that the break-down of the suction capacity curve was a consequence of cavitation appearing on the pressure side of the blade.

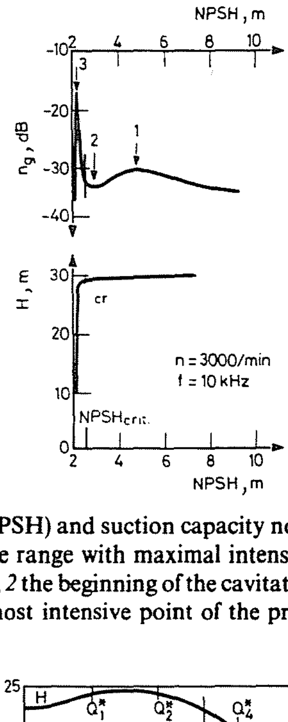

Fig. 23. Suction capacity ($H-$NPSH) and suction capacity noise level (n_g-NPSH) curves with marks of critical states (cr); *1* the range with maximal intensity of cavitation appeared on the suction side of the impeller blade, *2* the beginning of the cavitation appearing on the pressure side of the blade, *3* the most intensive point of the pressure side cavitation

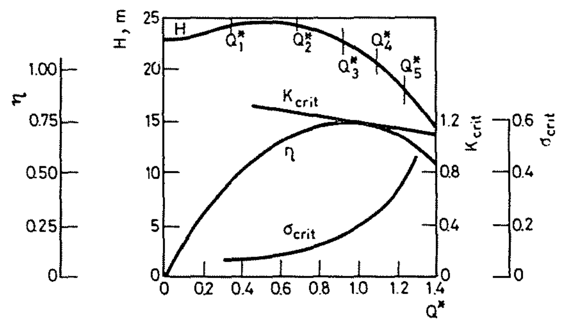

Fig. 24. Characteristics of a pump with cavitation limit curve (H head, $Q^x = Q/Q_{opt}$ relative flow rate, $\sigma_{crit} = \mathrm{NPSH}_{crit}/H$ the cavitation limit curve, K_{crit} cavitation limit curve.)

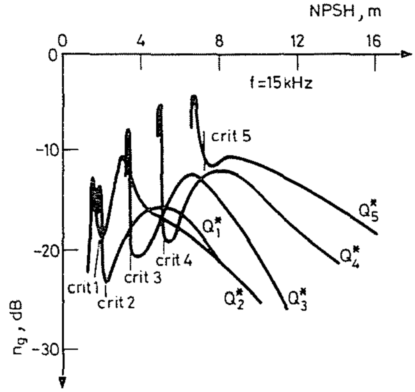

Fig. 25. Suction capacity — noise level curves. Noise level (n_g) in the function of the cavitation reserve (NPSH). Frequency: f= 15 kHz

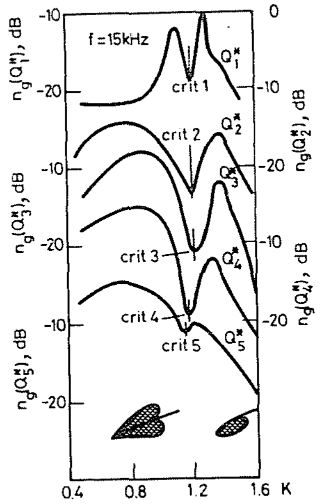

Fig. 26. Suction capacity — noise level curves. Noise level (n_g) in the function of cavitation number (K) with relative flow-rate ($Q^* = Q/Q_{opt}$) as parameter. The figures below refer to the places of zone development

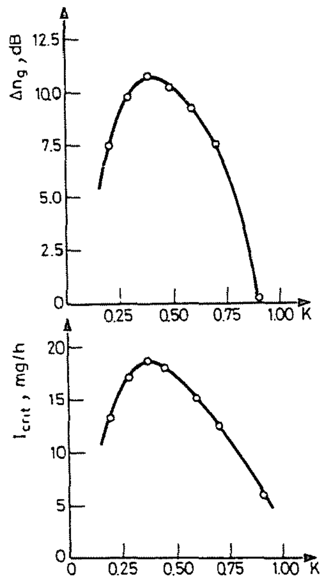

Fig. 27. The change of noise level (Δn_g) and erosion intensity (I_{crit}) in the function of cavitation number (K) in tests performed on a pump impeller with constant flow-rate

We previously referred (Fig. 6) to the fact that for cavitation appearing on the pressure side of the impeller blade NPSH is not suitable as a cavitation number. In the case of suction capacity — noise level curves drawn by using cavitation number K of the second type the appearance of the pressure side cavitation happens in a narrow range of cavitation number. This circumstance can be deduced from the supposition of "same cavitation state — same cavitation number" (Fig. 26) [38].

The values of critical cavitation number (K_{crit}) lie on the same straight line in the figure (Fig. 24) containing the characteristic. So in the course of suction capacity investigation the range of the critical suction head of the pump can be determined by consideration of relation $K_{crit} = K_{crit}(Q)$

$$K_{crit} = \frac{\left(0.97 - \frac{k}{2}\right) H + \mathrm{NPSH}_{crit} - \frac{c_2^2}{2g} - h}{u_2^2/2g}$$

Finally the analogy of Fig. 12 is shown in Fig. 27 concerning the erosion and/or noise characteristics of cavitation appearing in pumps at $Q = \text{constant}$ [39].

Conclusions

1. The results of cavitation investigations indicate the fact that cavitating flow is a territory of flow which has its own laws independently of the place and form of appearance and differs qualitatively from non-cavitating flows. The two flow ranges are connected with each other by a transition where the laws of non-cavitating flow are predominantly effective.

2. The laws of cavitating flow can be described with properly chosen cavitation numbers. The characteristics of the flow are the extent of cavitation, its periodicity and its kinematic structure.

3. The cessation of the periodically formed hollows is started with macrojets entering the cavities. The erosion and the noise accompanying the cavitating flow are in direct connection with the jets.

4. The development of the cavitation configuration and the increase in noise level correspond to each other only in the incepting period of cavitation, then contrary to a further growth in zone (supercavitation) the intensity of the noise decreases.

5. The noise level curves show direct correlation to the erosion intensity curves.

6. The critical suction values of the pump mean an analogous cavitation state.

7. Data gained by noise tests advantageously complete the hydraulic characteristics of the pump and in certain places can substitute them.

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