NOISE MEASURING AS A COMPLEMENTARY AND CHECKING METHOD FOR PUMP TESTING

By

J. VARGA and GY. SEBESTYÉN

Department of Hydraulic Machines, Technical University, Budapest

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1. Introduction

The investigation of cavitational flow from the viewpoint of acoustics, the development of methods for examining the occurring noise and vibration phenomena yielded results which were important for practical purposes as well and, at the same time rendered the measurements of noise and acceleration levels a serviceable means for forming an opinion of the cavitation behaviour of hydraulic machines. It is a way that yields information which is without visual observation more ample than the drop of the head-capacity and efficiency curves and cannot be determined by any other means. Namely, the onset of cavitation, or the change in its intensity, can only be deduced from the drop in the characteristic curves, when visual observation is impossible; but those data do not give any information whatever as to the intensity of the cavitation, or of the changes in the cavitation with different values of the cavitation number. Further, no information is available of the occurrence of such cavitation processes in the machine examined, as do not influence the characteristic curves of pumps yet may have other harmful effects (e.g. erosion). The former can be simply detected by acoustical methods.

The bases for introducing this method into practice are given in the following main research work results:

1. The noise levels determined at different stages of cavitation, above a certain frequency limit, depend basically on the cavitation conditions and therefore within a certain frequency range the measurements of noise level can be made at a discretionary frequency and the results yield information as to the occurring cavitation phenomena [1, 2].

2. The results of the experimental research work in the field of cavitational flow and cavitation erosion connected with the results of the simultaneously performed acoustic investigations have shown that there is an unequivocal correlation between cavitation conditions and cavitation erosion and their respective noise level. Aforesaid is illustrated in Fig. 1 where the relative cavity length (λ) behind circular cylinder model placed in the cavitation

tunnel and the noise level values (Δn_g) are illustrated as a function of the cavitation number. From the diagram it is obvious that the character of the noise level curve is governed by the cavitation conditions and their variations [3–7].

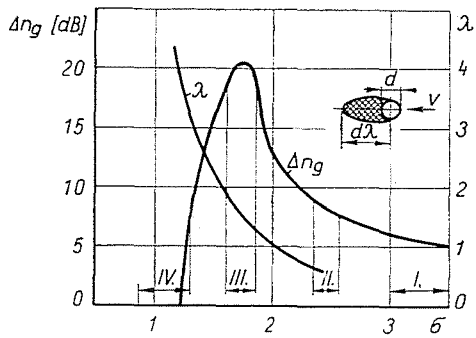

Fig. 1

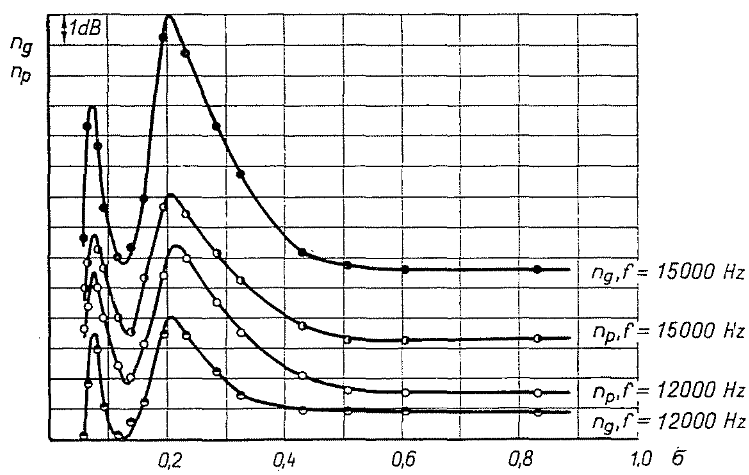

Fig. 2

3. The noise level curve has characteristic ascending and descending sections, such as the beginning of cavitation (I), the periodic shedding of cavities (II), the section of highest intensity (III), and the section of the exhaustion of the cavitation (IV), which corresponds to the blocking state (choking-flow) in the cavitation tunnel.

4. In a single machine there may appear several kinds of cavitation at the same time (e.g. clearance and blade cavitation); but the character of the cavitation noise level curve does not change, only there are as many peak

values appearing on the curve as the number of the kinds of cavitation by way of the superposition of the isolated cavitations. Fig. 2 presents the results of measurements of sound pressure level and acceleration level made in a pump at two different frequencies. It can be seen that the character of the noise level curves, within the appropriately chosen frequency range, is independent of the frequency number and the way of sensing (whether noise level or acceleration level measuring). The curves have two peaks, one appearing at a higher, the other at a lower cavitation number, indicating that in the pump two kinds of cavitation are occurring. The cavitation numbers corresponding to the second (left-hand side) peak of the noise level curves coincide with certain break-off in the head [3, 8]. The cavitation number σ is defined by $\sigma = (p_\infty - p_v)/(0.5\,\varrho\, v^2)$, where p_∞ is the static pressure in the place of the model, p_v is the vapor pressure, ϱ is the liquid density and v indicates the mean velocity of undisturbed flow.

2. Method of measurement

The method of measurement and its successful employment in investigating hydraulic machines has been described in detail in earlier publications of the authors [1, 3]; therefore now only a few of the more important data of

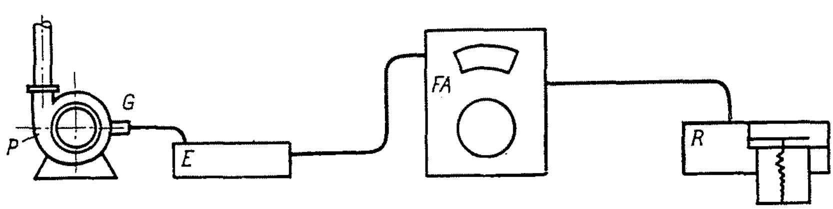

Fig. 3

the method are referred to. Brüel and Kjaer acceleration sensors (G) measuring in the 20—20 000 Hz range were placed on the spiral volute casing of the pumps (P) to be examined (Fig. 3). The electric signals received were introduced through an amplifier (E) into a frequency analyser (FA) connected to a level recorder (R). Measurement of the hydraulic characteristics of the pumps was made by traditional methods. In the course of investigations the acceleration values of the vibrations were measured, and the levels were calculated from the correlation

$$n_g = 10 lg \left(\frac{g^*}{g}\right)^2 \qquad (1)$$

where g^* is the value of the measured, while g is that of the gravitation acceleration. Fig. 4 contains the frequency-spectrum curves taken in the 6.3—20 kHz range, with different discharge at constant geodetic suction head in a pump examined. The curves are with good approximation parallel, meaning

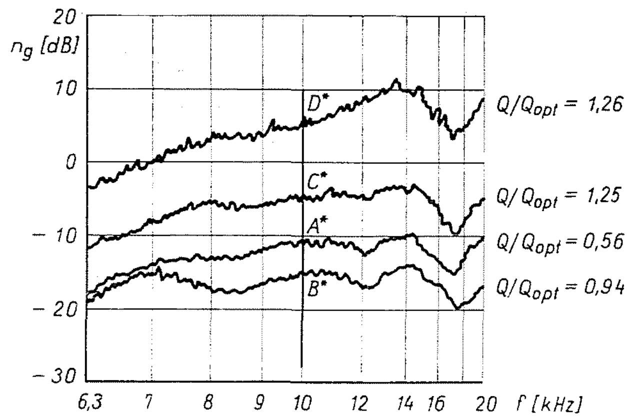

Fig. 4

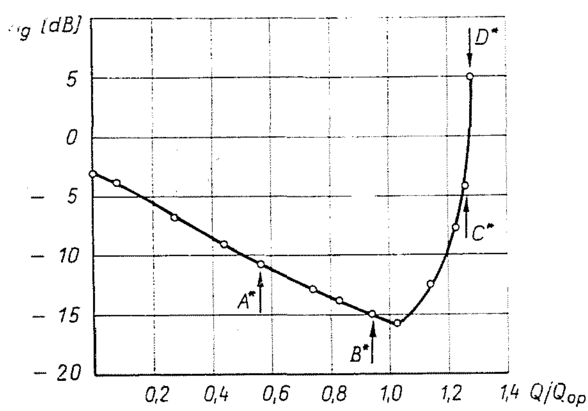

Fig. 5

that the investigations can be made at any arbitrarily chosen frequency. From such frequency-spectrum curves *the noise level performance curve of the pump* as function of the rate of flow can be constructed. Fig. 5 shows such a curve as a function of the relative discharge. The curve was drawn according to the values belonging to 10 kHz of the frequency-spectrum. Points A^*, B^*, C^*, D^* in Fig. 4 are marked in this figure.

3. Further informations to be gained from the acoustic examination of the pumps

Fig. 6 presents the head-capacity, efficiency and noise level performance curves of a pump, drawn in relative scales (related to the values belonging to the point of highest efficiency), where H is the delivery head, Q is the discharge, η is the efficiency of the pump, Δn_g is the difference of the acceleration levels measured in different working conditions and at the highest efficiency point. Curve Δn_g has its minimum value at the highest efficiency point. Right of the minimum value the acceleration level curve rises steeply indicating the

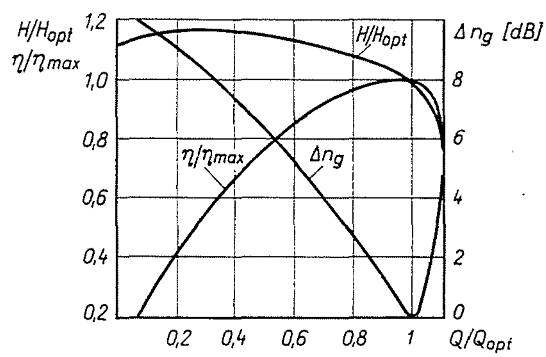

Fig. 6

occurrence of cavitation marked also by the sudden drop of the H and η curves. The curves show a fairly steep rise left of the minimum point, too, indicating that the pump had worked with cavitation already before the sudden change in the head-capacity and efficiency curves. Thus the widespread view that no cavitation occurs before the sudden changes in the characteristic curves cannot be maintained any longer. The pump examined works without cavitation only in the neighbourhood of the maximum efficiency point. The character of the noise level curve for a pump working cavitation-free with small discharges is presented in Fig. 7.

The so-called *suction capacity noise level curves* (NPSH — n_g) taken at the investigation of the suction capacity of the pumps and the pump noise level curves (Q — n_g) taken at constant number of revolutions and constant geodetic suction head of the pumps are in close correlation. The suction capacity noise level curves belonging to the A, B, C and D points of the pump noise level curve shown in Fig. 8 are illustrated in Fig. 9. The close connexion between the two curves is also shown by the fact that the n_{gA}, n_{gB}, etc. points of Fig. 8 are the points belonging to the highest NPSH in Figs 9A, 9B, etc. The noise level curves of the suction capacity shown in Fig. 9 were taken at 20 kHz frequency, but within the frequency range determined according to the considerations mentioned above these curves can also be taken at any frequency and will yield identical results. This is verified by Fig. 10, where the resulting noise level curve (d) belonging to the value $Q_A/Q_{opt} = 0.38$, as well as the noise

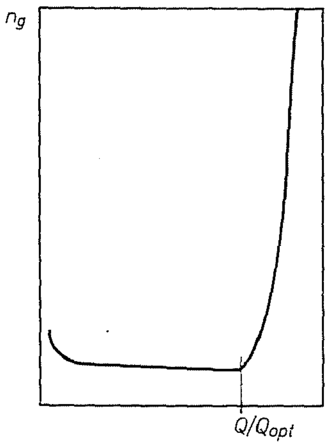

Fig. 7

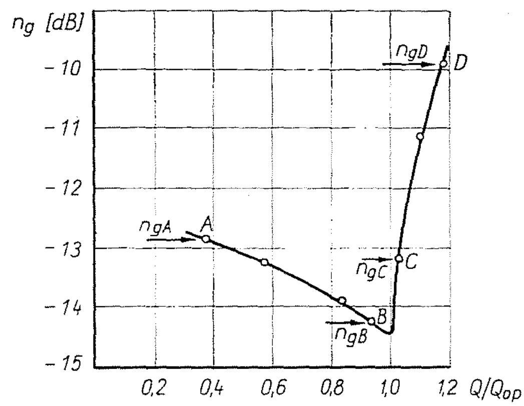

Fig. 8

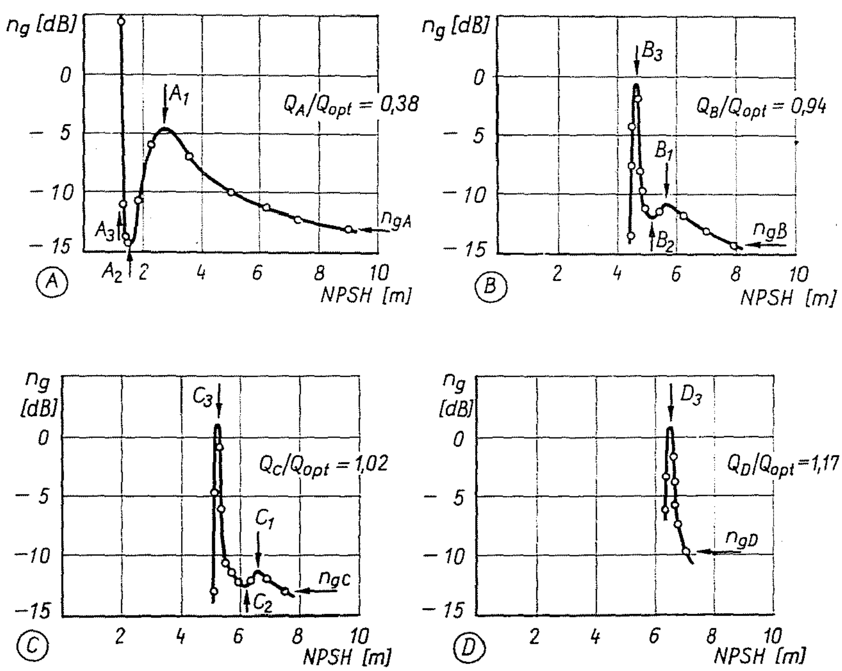

Fig. 9

level curves taken at frequencies 20, 14, and 10 kHz (c, b, a resp.) can be seen. The NPSH values were determined by the usual correlation

$$\mathrm{NPSH} = \frac{p_1 - p_r}{\gamma} + \frac{c_1^2}{2g} \tag{2}$$

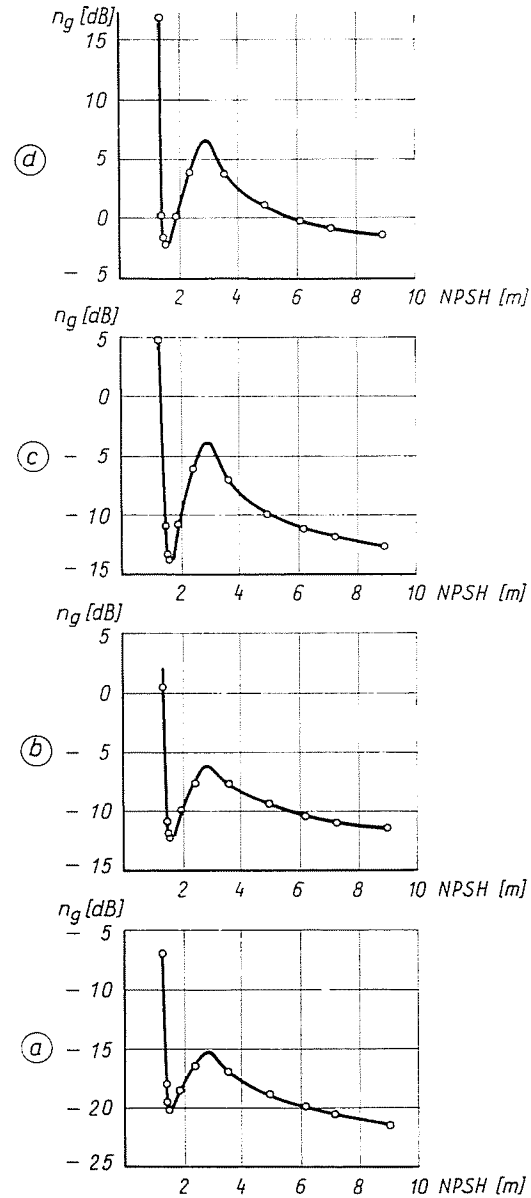

Fig. 10

where p_1 is the pressure to be measured in the suction cover of the pump, γ is the specific gravity of the delivered fluid, c_1 is the mean velocity in the suction pipe.

Returning to the suction capacity noise level curves shown in Fig. 9, these are usually curves disclosing two peak values where the smaller peak value refers to the cavitation on the suction side while the second, bigger one to the cavitation on the pressure side. The recurring line of the second peak on the curve marked A could not be followed by measurements because of

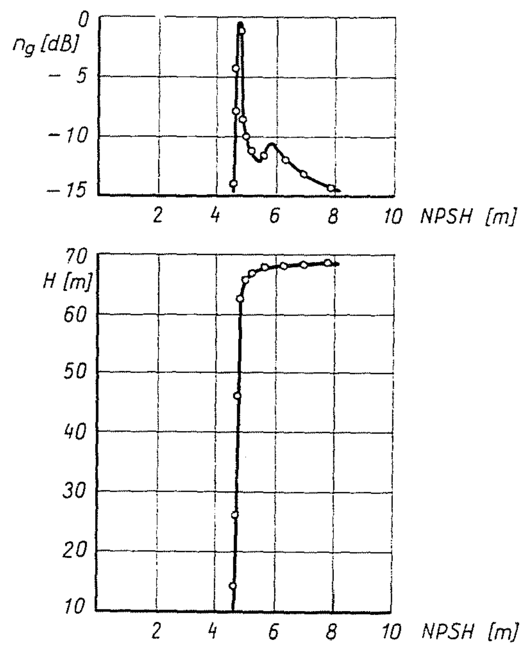

Fig. 11

the appearance of strong vibrations. The figure allows to conclude to a fully developed cavitation on the suction side, in point A_1. With increasing discharge (Figs B and C) a considerable decrease in the suction side cavitation can be observed (B_1 and C_1). The simultaneous change in the head and the noise level curves is shown in Fig. 11 for case B of the figure series 9. It must be noted that for the determination of the peak indicating the size of the pressure side cavitation the presentation in the function of NPSH is not fully adequate since NPSH is not really a cavitation characteristic. For this purpose the noise level measurement taken as function of the cavitation number is suitable. However, interesting conclusions can be drawn from the curves. Thus, for instance, in case D of the Fig. 9 series it can be determined that there is developed pressure side cavitation belonging to the maximum NPSH value; the cavitation reaches its maximum intensity and full exhaustion in a comparatively narrow NPSH range, when the blade channels of the impeller are partly filled in by the cavity and it decreases the useful cross section for delivery considerably.

For the qualification of pumps it is customary to indicate the $(\mathrm{NPSH})_{\mathrm{krit}}$, or $\sigma_{p\,\mathrm{krit}}$ values, as functions of the flow rate. By agreement, these critical values mean the NPSH and σ_p values belonging to 1—3% decrease of the head, respectively. In Fig. 12 are represented the NPSH values belonging to the

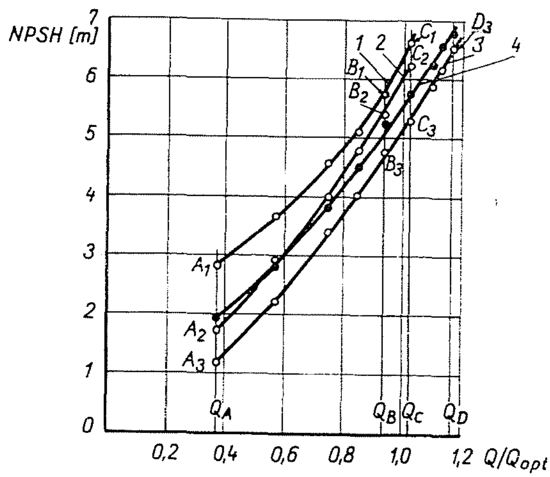

Fig. 12

peaks and minimums in Fig. 9 as function of the relative discharge. They are marked with the same numbers as the subscripts in Fig. 9. The curve marked with the number 4 shows the $(\mathrm{NPSH})_{\mathrm{krit}}$ values defined by a value belonging to 3% decrease in the head. Fig. 13 contains the σ_p values as functions of the relative discharge calculated from the correlation

$$\sigma_p = \frac{\mathrm{NPSH} - \dfrac{d_1}{2}}{H}$$

and

$$\sigma_{p\,\mathrm{krit}} = \frac{(\mathrm{NPSH})_{\mathrm{krit}} - \dfrac{d_1}{2}}{H} \tag{3}$$

where d_1 is the inlet diameter of the impeller and H is the head belonging to the given discharge on the head-capacity curve of the pump. These curves carry physical content and they justify the fact that the conventionally used curve belongs really to the incipient stage of the cavitation on the pressure side.

In course of the investigations the authors strove to establish a cavitation coefficient that gives a better reflection of the conditions under which cavitation occurs than the NPSH or $\sigma_{p\,\mathrm{krit}}$ values; this cavitation coefficient is

$$\varkappa = \frac{p_2 - p_r}{(\varrho/2)\, u_2^2} \tag{4}$$

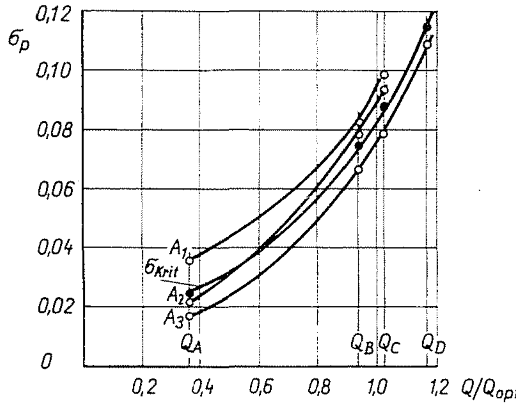

Fig. 13

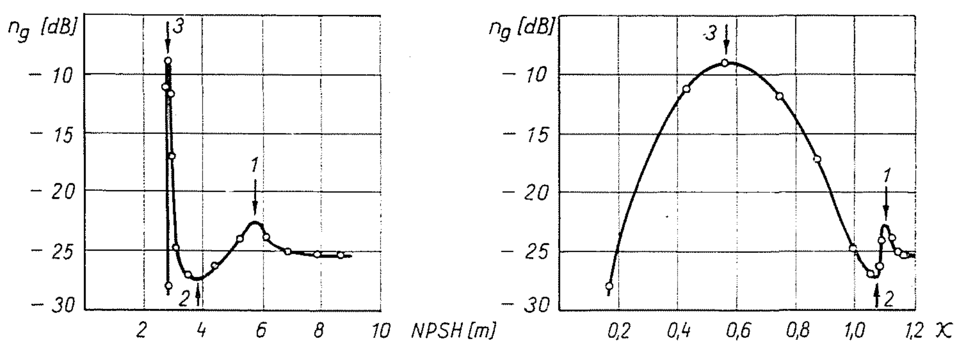

Fig. 14

where in the numerator the difference between the pressure corresponding to the delivery head and the vapour pressure appears, while in the denominator, u_2 signifies the peripheral velocity of the impeller. Fig. 14 presents the noise level curve taken as a function of the suction capacity and a function of the cavitation coefficient according to Eq. (4). The latter curve gives good indication as to the cavitation of the pump. It is verifiable from the curve that there is a comparatively insignificant cavitation on the suction side (marked 1), while it shows also the cavitation on the pressure side influencing the working conditions of the pump (point marked 3). The character of the curve, by the way, shows good coincidence with that of the noise level curve taken in the hydrodynamic tunnel (Fig. 1), and the characteristic sections can be found here, too.

The noise level measurements are very sensitive in indicating changes in the air content as well. Fig. 15 is a good illustration of that. Section L_1 of the curve in the figure shows the results of noise level measuring, when air intruded into the pump through a little crack in the suction pipe of the pump. Attention is called to this irregularity by the sinking initial section of the noise level curve, as this initial section should be slightly rising, or horizontal. After stopping the intrusion of air the noise level measurement resulted in curve L_2.

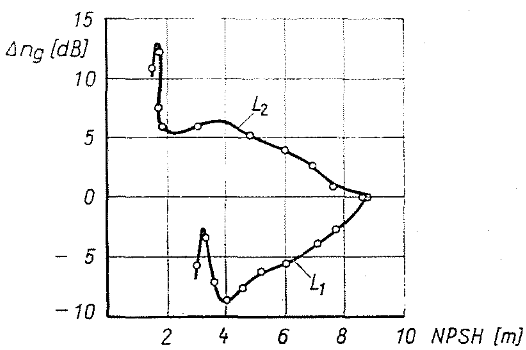

Fig. 15

4. Evaluation of the results

A considerable number of investigations made with one-stage, open and closed impeller-type as well as double flow path pumps clearly indicate the fact that the noise level curve marks with sufficient accuracy the place of the maximum efficiency point; the character of the curve also gives informations as to whether cavitation must be counted with before the maximum efficiency point. At the same time it shows the correlation between the development of cavitation and the characteristic curves in the range $Q/Q_{\text{opt}} > 1$. The suction capacity noise level curves yield information about the types and intensity of the cavitation in the impeller and give a concrete content to the NPSH values customary by pump investigations. The noise level curve of the pump and the noise level curve of the suction capacity as well as the conventional suction capacity curve are closely interconnected.

The results also indicate that the noise level investigations of pumps will give more ample and new information as to the working conditions of the pumps. The cavitation conditions of the pumps are enlightened throughout the full delivery range. For characterising the cavitation conditions of the pumps the authors have introduced the cavitation coefficient $\varkappa$ giving better characterisation of the cavitational behaviour of hydraulic machines. Noise level measurements increase the reliability of hydraulic measurements and give a basis to the designers for estimating the cavitation behaviour of the impeller and the pump.

Summary

Results of noise level measurement method developed for acoustic detection of cavitation phenomena and applied for investigation of pumps. Without visual observation, the method yields more information than the hydraulic characteristics by making noise level measurements on a single properly chosen frequency. The noise level curves belonging to the characteristic curves of the pumps and to the suction capacity curves serves for the determination of the cavitation conditions of the pumps in the full delivery range.

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Prof. Dr. József VARGA
Dr. Gyula SEBESTYÉN
Budapest XI., Sztoczek u. 2—4. Hungary.